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3GPP

Postal address

3GPP support office address

650 Route des Lucioles - Sophia Antipolis
Valbonne - FRANCE
Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Internet

http://www.3gpp.org

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Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

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x the first digit:

1 presented to TSG for information;

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y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z the third digit is incremented when editorial only changes have been incorporated in the document.

Introduction

A study item, “Feasibility Study on LTE-based V2X Services”, was approved at 3GPP TSG RAN #68 [2]. This study is to evaluate new functionalities needed to operate LTE-based V2X services defined in [3]. The objectives of the study include definition of an evaluation methodology and possible scenarios for vehicular services based on LTE, and identification and evaluation of necessary enhancements to LTE physical layer, RAN protocols, and interfaces. The results and findings of the study are documented in this technical report.

1 Scope

The present document contains the results and findings from the study item, "Feasibility Study on LTE-based V2X Services" [2]. The purpose of this TR is to document the identified LTE enhancements and corresponding evaluations for LTE-based V2X services defined in [3] as follows:

- V2V (vehicle-to-vehicle): covering LTE-based communication between vehicles.
- V2P (vehicle-to-pedestrian): covering LTE-based communication between a vehicle and a device carried by an individual (e.g. handheld terminal carried by a pedestrian, cyclist, driver or passenger).
- V2I/N (vehicle-to-infrastructure/network): covering LTE-based communication between a vehicle and a roadside unit/network. A roadside unit (RSU) is a stationary infrastructure entity supporting V2X applications that can exchange messages with other entities supporting V2X applications. Note: RSU is a term frequently used in existing ITS specifications, and the reason for introducing the term in the 3GPP specifications is to make the documents easier to read for the ITS industry. RSU is a logical entity that combines V2X application logic with the functionality of an eNB (referred to as eNB-type RSU) or UE (referred to as UE-type RSU).

This document addresses LTE-based V2X both with and without LTE network coverage, and covers both the operating scenario where the carrier(s) is/are dedicated to LTE-based V2X services (subject to regional regulation and operator policy including the possibility of being shared by multiple operators) and the operating scenario where the carrier(s) is/are licensed spectrum and also used for normal LTE operation.

This technical report contains the evaluation methodology for LTE-based V2V, V2I/N and V2P services to compare the performance of different technical options.

This document identifies necessary enhancements to LTE for support of PC5 transport for V2V services.

This document captures identification and evaluation of Uu transport for V2V and PC5/Uu transport for V2I/N and V2P services.

This document is a 'living' document, i.e. it is permanently updated and presented to TSG-RAN meetings.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] 3GPP TD RP-151109: "New SI proposal: Feasibility Study on LTE-based V2X Services".

[3] 3GPP TR 22.885: "Study on LTE Support for V2X Services".

[4] 3GPP TR 36.843: "Study on LTE Device to Device Proximity Services".

[5] 3GPP TR 36.828: "Further enhancements to LTE Time Division Duplex (TDD) for Downlink-Uplink (DL-UL) interference management and traffic adaptation".

[6] ETSI TR 101 612: "Intelligent Transport Systems (ITS); Cross Layer DCC Management Entity for operation in the ITS G5A and ITS G5B medium; Report on Cross layer DCC algorithms and performance evaluation".

[7] 3GPP TR 36.814: "Further advancements for E-UTRA physical layer aspects".

[8] R1-157436, "Discussion on DMRS density and structure to handle high Doppler case."

[9] R1-157435, "Discussion on enhancement for PC5 based V2V resource allocation."

[10] R1-157449, "Further discussion on resource allocation mechanism in PC5-based V2V."

[11] R1-157438, "Discussion on Resource Allocation Enhancement for PC5 based V2V Communications."

[12] R1-156690, "On enhancements to resource pool configuration for V2V communication."

[13] R1-156687, "Discussion on baseline sidelink performance for V2V communication."

[14] R1-156688, "On support of geo-based transmission for V2V communication."

[15] R1-157534, "Discussion on enhancement of V2X resource allocation."

[16] R1-157777, "Enhancement of resource allocation and procedure for V2V."

[17] R2-161800, "Summary of email discussion on [92#45][LTE/V2X] Capacity Analysis."

[18] R1-165403, "Evaluation results on the enhancement of Uu transport for V2V, V2P and V2I/N."

[19] R1-163182, "Evaluation of Uu transport for V2x communications."

[20] R1-164158, "Performance analysis of Uu broadcast transmission schemes for V2V communication."

[21] R1-160644, "Discussion on the enhancement for supporting eNB type RSU."

[22] R1-161504, "Initial evaluation for PC5 based V2I/I2V and Uu based I2V communication."

[23] R1-164206, "Further consideration on UE autonomous resource allocation in PC5-based V2V."

[24] R1-164510, “Discussion on details of sensing operation for PC5 based V2V.”

[25] R1-164535, “Evaluation results on PC5 transport for V2P and V2I/N.”

[26] R1-165207, “Evaluation of PC5 transport for V2P/V2I/I2V communications.”

[27] R1-165208, “Further detail of partial sensing for P2V operation.”

[28] ETSI EN 302 637-2 V1.3.2 (2014-11), Intelligent Transport System (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service.

[29] R1-163062, "PC5 for V2V and V2P."

[30] R1-162496, "Evaluation results on the enhancement of Uu transport for V2V."

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in TR 21.905 [1] and the following apply.
A term defined in the present document takes precedence over the definition of the same term, if any, in TR 21.905 [1].

3.2 Symbols

For the purposes of the present document, the following symbols apply:

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1] and the following apply.
An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1].

P-UE	Pedestrian UE
V-UE	Vehicle UE

4 V2X operation scenarios

4.1 Scenario 1

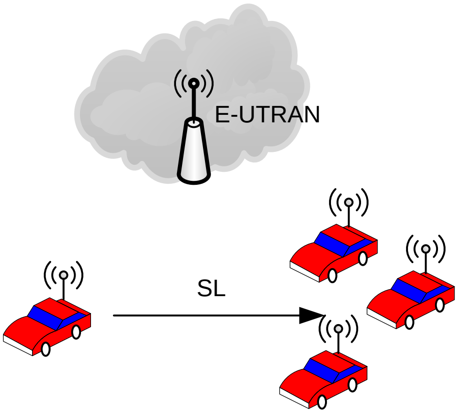
4.1.1 General Description

This scenario supports V2X operation only based on PC5.

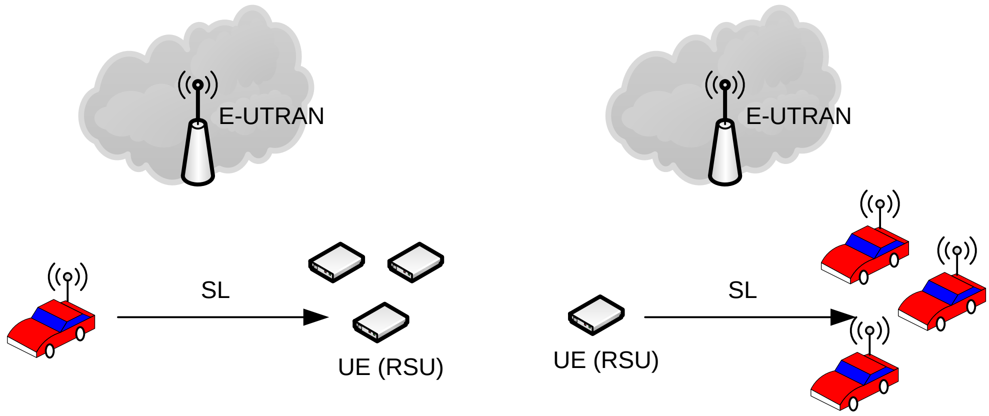
In this scenario, a UE transmits a V2X message to multiple UEs at a local area in sidelink.

For V2I, either transmitter UE or receiver UE(s) are UE-type RSU.

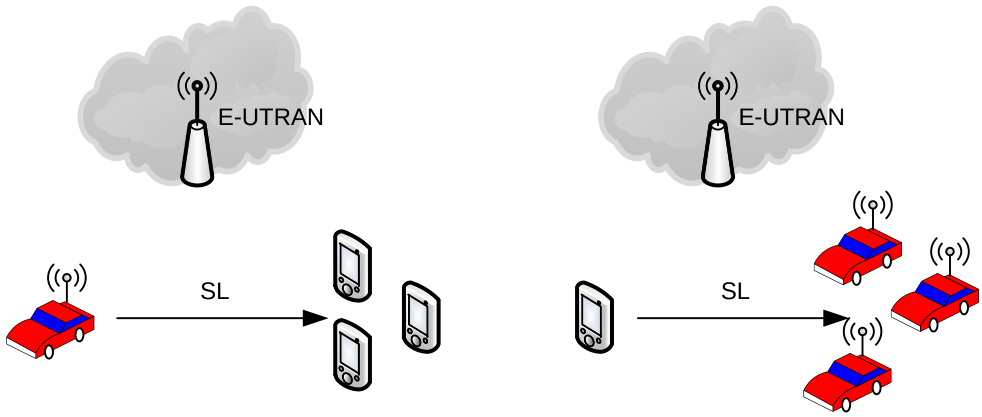
For V2P, either transmitter UE or receiver UE(s) are pedestrian UE.



(a) V2V operation



(b) V2I operation



(c) V2P operation

Figure 4-1: Scenario 1

4.1.2 Operation Aspects

RAN aspects for PC5-based V2X operation (Tx/Rx of V2X message) are as follows:

- (Aspect 1) Operation bands used as test points for evaluation
  - Case 1A: 6 GHz
  - Case 1B: 2 GHz

  Note: Case 1B may not be need to be specifically simulated for all scenarios
- (Aspect 2) eNB deployment consideration including possibility of network control
  - Case 2A: UE autonomous resource allocation, at least mode 2, based on semi-statically network-configured/pre-configured radio parameters including no eNB coverage case.
  - Case 2B: eNB providing more UE specific or/and more dynamic resource allocation including Mode 1 compared to case 2A.

  Note: Related to aspect 2, it is necessary to consider the condition to apply any preconfigured radio parameters.
- (Aspect 3) Multi-carrier operation
  - Case 3A: UEs communicating over PC5 across a single carrier.
  - Case 3B: UEs communicating over PC5 across multiple carriers.
- (Aspect 4) Operating scenarios
  - Case 4A: Single operator operation
  - Case 4B: A set of PC5 operation carrier(s) is shared by UEs subscribed to different operators. This means that UEs belonging to different operators may transmit on the same carrier.
  - Case 4C: Each operator is allocated with a different carrier. This means that a UE transmits only on the carrier allocated to the operator which it belongs to.
  - FFS: Case 4D: No operator operation

- (Aspect 5) Co-existing with Uu
  - Case 5A: Dedicated carrier for V2x. There is no uplink (Uu) traffic on the PC5 operation carrier.
  - Case 5B: V2x carrier is shared with Uu.

All scenarios and combinations captured above should be considered in scope of the study item.

4.2 Scenario 2

4.2.1 General Description

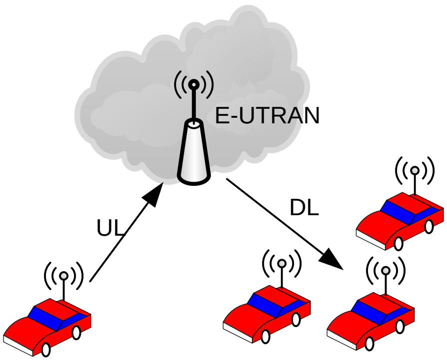
This scenario supports V2X operation only based on Uu.

In this scenario,

- For V2V and V2P, a UE transmits a V2X message to E-UTRAN in uplink and E-UTRAN transmits it to multiple UEs at a local area in downlink.
- For V2I, when receiver is eNB type RSU, a UE transmits a V2I message to E-UTRAN(eNB type RSU) in uplink; when transmitter is eNB type RSU, E-UTRAN(eNB type RSU) transmits a I2V message to multiple UEs at a local area in downlink.
- For V2N, the UE communicates with an application server (e.g. traffic safety server).

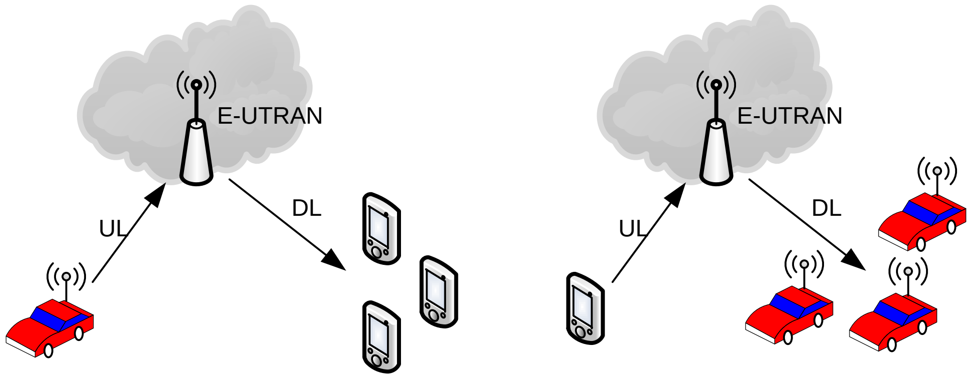
For V2P, either transmitter UE or receiver UE(s) are pedestrian UE.

To support this scenario, E-UTRAN performs uplink reception and downlink transmission of V2X messages. For downlink, E-UTRAN may use a broadcast mechanism. It is FFS whether E-UTRAN supports RSU for V2V and V2P operation.

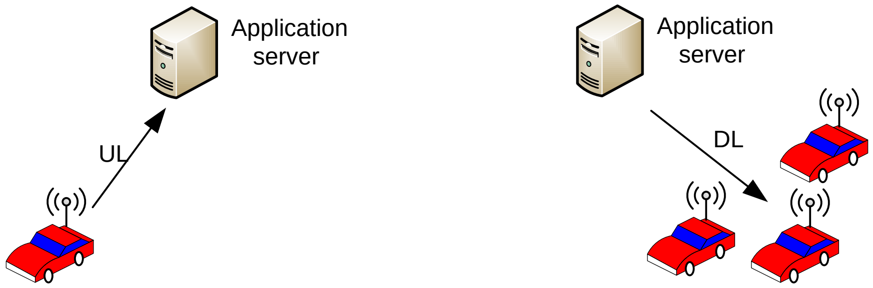


(a) V2V operation

(b) V2I operation



(c) V2P operation



(d) V2N operation

Figure 4-2: Scenario 2

4.2.2 Operation Aspects

RAN aspects for Uu-based V2X operation (Tx/Rx of V2X message) in this scenario are as follows:

- **(Aspect 1) Operation bands used as test points for evaluation**
  - Case 1A: 6 GHz
  - Case 1B: 2 GHz

NOTE: Case 1A may not be needed to be specifically simulated for uplink and downlink.

- **(Aspect 2) eNB deployment consideration including possibility of network control**
  - eNB deployment and network control for radio resources are always assumed in uplink and downlink.
- **(Aspect 3) Multi-carrier operation**

  For UL:
  - Case 3A-UL: UEs performing uplink transmissions at a single carrier for V2X messages.
  - Case 3B-UL: UEs performing uplink transmissions across multiple carriers for V2X messages.

  For DL:
  - Case 3A-DL: UEs performing downlink receptions at a single carrier for V2X messages.
  - Case 3B-DL: UEs performing downlink receptions across multiple carriers for V2X messages.

- **(Aspect 4) Operating scenarios**
  - Case 4A: Single operator operation (i.e. message exchange across operators are not assumed.)
  - Case 4B: A set of Uu operation carrier(s) is shared by UEs subscribed to different operators.
    - In this case, UEs belonging to different operators transmit on the shared uplink carrier(s) while receiving on the shared downlink carrier(s).
  - Case 4C: Each operator is allocated with a different carrier for both uplink and downlink.
    - In this case, a UE transmits only on the uplink carrier(s) allocated to the operator to which it belongs. The UE may receive on multiple DL carriers, i.e., UE receives on the downlink carrier allocated to the other operator as well as the downlink carrier allocated to the operator to which it belongs.
    - A UE is allowed to receive downlink broadcast of other operator.

NOTE: The study excludes the case that each operator is allocated with a different uplink carrier while a set of downlink operation carrier(s) is shared by UEs subscribed to different operators. The study excludes the case that a set of uplink operation carrier(s) is shared by UEs subscribed to different operators while each operator is allocated with a different downlink carrier.

- **(Aspect 5) Co-existing with Uu/sidelink**
  - Case 5A: There is no sidelink traffic on the Uu operation carrier.
  - Case 5B: The uplink carrier is shared with sidelink.
- NOTE: It is FFS whether the uplink carrier can be the dedicated operation carrier for V2X.

- **(Aspect 6) Single/multiple eNB**
  - Case 6A: Uplink reception and downlink transmission for the same message are performed by the sa me eNB.
  - Case 6B: Uplink reception and downlink transmission for the same message are performed by differe nt eNBs.
    - In this case, uplink reception is performed by one eNB. But downlink transmission can be performed by different eNB(s) including the eNB which received the message.

4.3 Scenario 3

4.3.1 General Description

This scenario supports V2V operation using both Uu and PC5.

NOTE: The study deprioritizes Scenario 3.

4.3.1.1 Scenario 3A

In this scenario, a UE transmits a V2X message to other UEs in sidelink. One of the receiving UEs is a UE type RSU which receives the V2X message in sidelink and transmits it to E-UTRAN in uplink. E-UTRAN receives the V2X message from the UE type RSU and then transmits it to multiple UEs at a local area in downlink.

To support this scenario, E-UTRAN performs uplink reception and downlink transmission of V2X messages. For downlink, E-UTRAN may use a broadcast mechanism. It is FFS whether E-UTRAN also supports RSU function in this scenario.

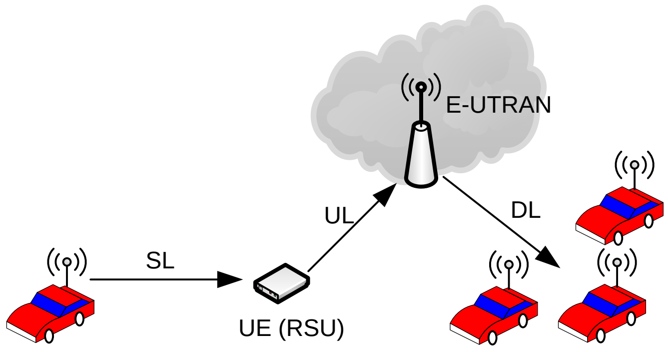


Figure 4-3: Scenario 3A

4.3.1.2 Scenario 3B

In this scenario, a UE transmits a V2X message to E-UTRAN in uplink and E-UTRAN transmits it to one or more UE type RSUs. Then, the UE type RSU transmits the V2X message to other UEs in sidelink.

To support this scenario, E-UTRAN performs uplink reception and downlink transmission of V2X messages. For downlink, E-UTRAN may use a broadcast mechanism. It is FFS whether E-UTRAN also supports RSU function in this scenario.

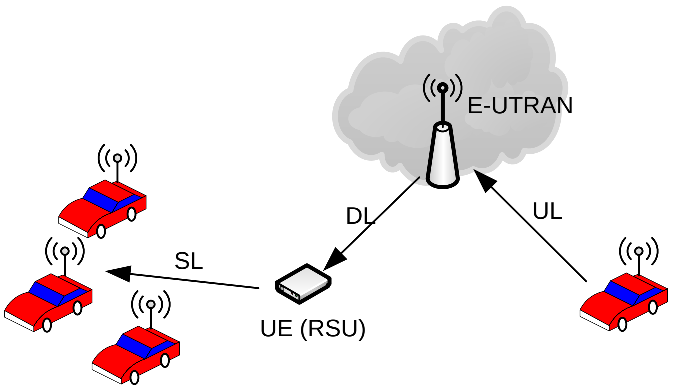


Figure 4-4: Scenario 3B

4.3.2 Operation Aspects

RAN aspects for Uu/PC5-based V2V operation (Tx/Rx of V2X message) in this scenario are as follows:

- **(Aspect 1) Operation bands used as test points for evaluation**

  For PC5:

  – Applying all the cases in the corresponding aspect of Scenario 1.

  For Uu:

  – Applying all the cases in the corresponding aspect of Scenario 2.

NOTE: Evaluation work on V2V for this aspect will focus on the combination of {1A for PC5, 1B for Uu} in Scenario 3.

- **(Aspect 2) eNB deployment consideration including possibility of network control**

  For PC5:

  – Applying all the cases in the corresponding aspect of Scenario 1.

  For Uu:

  - Applying all the cases in the corresponding aspect of Scenario 2.

- **(Aspect 3) Multi-carrier operation**

  For PC5:

  - Applying all the cases in the corresponding aspect of Scenario 1.

  For UL:

  - Applying all the UL cases in the corresponding aspect of Scenario 2.

  For DL:

  - Applying all the DL cases in the corresponding aspect of Scenario 2.

- **(Aspect 4) Operating scenarios**

  For PC5:

  - Applying all the cases in the corresponding aspect of Scenario 1.

  For Uu:

  - Applying all the cases in the corresponding aspect of Scenario 2.

  For both PC5 and Uu:

  - Case 4.1: PC5 operation carrier and Uu operation carrier are allocated to the same operator.
  - Case 4.2: PC5 operation carrier and Uu operation carrier are allocated to different operators.
    - In this case, it is assumed that uplink operation carrier and downlink operation carrier are allocated to the same operator. It is FFS whether uplink operation carrier and downlink operation carrier can be allocated to different operators.

- **(Aspect 5) Co-existing with Uu/sidelink**

  - Case 5A: Dedicated operation carrier for V2X on which there is sidelink traffic but no uplink (Uu) traffic, i.e. uplink and sidelink are on different carriers.
  - Case 5B: The uplink carrier is shared with sidelink, i.e. uplink and sidelink are on the same carrier.

NOTE: It is FFS whether the uplink carrier can be the dedicated operation carrier for V2X.

- **(Aspect 6) Single/multiple eNB**

  - Applying all the cases in the corresponding aspect of Scenario 2.

5 Technical support for V2V

5.1 PC5 interface

The design will be based on broadcast mechanism. No optimization is expected for unicast case in this release.

5.1.1 Resource allocation

It is observed that Rel-13 sidelink resource allocation is not sufficient for some of the scenarios for PC5-based V2V. Enhancements to Rel-13 sidelink resource allocation are necessary for PC5-based V2V

5.1.1.1 Resource pool

The resource allocation principles listed below should be studied for PC5-based V2V (note that other schemes are not precluded):

- Resource pool
  - The concept of resource pool is introduced at least for the purpose of study.
    - Resource pool is a set of time/frequency resources where PC5 transmission may occur. Note that Rel-12 D2D communication mode 1 uses all the time/frequency resources as data pool.
    - FFS whether Rel-12 resource pool configuration is reused for PC5-based V2V.
  - FFS the number of resource pools configured for a UE
    - The need for defining multiple resource pools should be justified.
    - FFS whether the number of SA pools can be different from the number of data pools and, if can, FFS whether multiple SA pools can be associated with the same data pool.

The following resource allocation principles are deemed necessary for PC5-based V2V:

- Scheduling assignment
  - Each data transmission is scheduled by an SA. A UE knows at least time and frequency location of data transmission(s) after decoding the associated SA.
    - FFS the indication is implicit, explicit, or both
  - If SA and the associated data from a single transmitter is transmitted in different subframes:
    - FFS details
  - If SA and the associated data from a single transmitter are transmitted in the same subframe:
    - FFS whether it is possible to support the case where data transmission in a subframe occurs without associated SA transmitted in the same subframe
    - Alt 1: SA and Data are transmitted on separate physical channels (i.e., separated DFT precoding for SA and data):
      - RAN1 assumes that RAN4 will study the proper transmission characteristics (e.g, MPR) to support this.
      - FFS whether SA and data transmissions in the same subframe are always adjacent in the frequency domain.
      - In case of separate channels, study whether SA pool and data pool are orthogonal or can overlap.
    - Alt 2: A single DFT precoding applies to SA and data transmitted in the same subframe.

        - The whole bandwidth is divided into one or multiple sub-channels.
        - The transmission bandwidth of SA/data is fixed to the bandwidth of a single sub-channel.
    - Alt 3: SA and data are TDMed within one subframe.
        - The transmission bandwidth of SA is fixed.
- Study the number of transmissions of a given TB
- Study the number of transmissions of a given SA
- FFS whether a single SA may schedule multiple TBs
- FFS whether the time/frequency resources of a given SA is independent of the time/frequency resources of the associated data

5.1.1.2 Resource control/selection mechanism

The resource allocation principles listed below should be studied for PC5-based V2V (note that other schemes are not precluded):

- Network control aspect
    - At least when a UE is inside coverage of an eNB on the carrier where PC5 is performed (i.e., Uu and PC5 share the carrier), the eNB controls at least some parameters that affects UE resource selection.
    - When a UE operates PC5 in a carrier where no cell is detected but it is inside coverage of an eNB in another carrier (i.e., different carriers for Uu and PC5), network may control at least some parameters that affects UE resource selection.
        - At least when the PC5 and Uu carriers are allocated to the same operator, RAN1 assumes that eNB has at least some controls. FFS for the other cases.
    - UE autonomous resource selection can be configured for a UE inside network coverage.
    - eNB control above includes
        - Exact resources for transmission or set of resources for UE autonomous selection
        - FFS: other parameters
- Enhancement to resource selection/structure
    - Study which of the following principle(s) is(are) beneficial:
    - Collision avoidance
        - A UE identifies the resources that will be occupied and/or collided by the other UEs and avoids a colliding resource allocation for its transmission.
        - FFS
            - Details of the identification of the occupied and/or collided resources, e.g., by reading other UEs' SA and/or sensing the energy level
            - How to select the resources and MCS for transmission
            - Whether a UE performs the resource selection procedure for every transmission, and if not, what triggers reselection

- FFS if the initial selection and reselection procedures are the same or not
  - Whether signaling from eNB (e.g., information on the resource load) or another UE is beneficial.
  - Whether resource in this context is in the physical domain or the logical domain
- Resource selection based on transmitter-specific information
  - Example 1: Resource allocation based on the location, velocity, and/or direction of the transmitter and/or distance between vehicles.
  - Example 2: A UE reports its observation on the radio environment to help eNB scheduling
- Enhanced resource randomization
  - Example is increasing the number of time resource patterns.
- Introducing a finer time resource granularity and/or a coarser frequency resource granularity
- Semi-persistent scheduling from eNB for PC5 transmissions
- Cross-carrier scheduling
  - eNB sends control via a carrier to schedule sidelink resource in another carrier not associated with the carrier used for the control transmission.
  - FFS in which scenario(s) this principle is beneficial

– Differentiation of radio transmission characteristics based at least on higher layer properties
  - FFS which other aspect(s) will also differentiate radio transmission characteristics
  - FFS radio transmission characteristics

– Transmission power control and/or setting
  - Use different transmission power e.g., depending on scenario
    - This includes the possibility of using zero power (i.e., muting)

– Resource allocation robust to temporal interruption due to, e.g., handover, RLF, cell reselection

The following observations are made for resource control/selection mechanism:

– For enhancement to UE autonomous resource selection, collision avoidance based on sensing (P1), enhanced random resource selection (P2), and location-based resource selection (P3) are shown to provide gain when each of them is evaluated individually.
  - Further discussion is needed to identify whether operating a combination of the principles provides more gain than operating an individual principle.
  - It is understood that a combination of P1 and P2 is possible at least in the following example:
    - In resource selection, a UE by sensing excludes the resources that will be occupied by other UEs, and the enhanced random selection applies to the remaining resources.
  - It is understood that a combination of P1 and P3 is possible at least in the following example:
    - Subsets of resources are associated with sets of UE location, and a UE performs P1 in the subset which is associated with its current location.

- It is understood that a combination of P2 and P3 is possible at least in the following example:
  - Subsets of resources are associated with sets of UE location, and a UE performs P2 in the subset which is associated with its current location.
- Details FFS

– RAN1 observes potential benefit of adapting transmitter behavior from physical layer viewpoint:

- It is noted that RAN1 has not evaluated the feasibility of any adaptation mechanism.
- FFS
  - Which specific behavior is adapted
    - E.g., Reducing message transmission rate and/or dropping some messages
  - What the adaptation is based on
    - E.g., when the vehicle density is high
  - Whether service requirement can be adapted accordingly in some scenarios

– RAN1 observes potential benefit of UE reporting its observation on the radio environment of PC5 carrier and/o r its location to help eNB scheduling. However, the uplink signaling overhead, handover issue, burden caused b y the increased number of RRC_Connected UEs have not been evaluated.

– RAN1 observes potential benefit of increasing subcarrier spacing. However, the impact of a smaller length of n ormal CP, ICI to/from legacy channels, AGC, timing advance, potential change in the inband emission have not been evaluated.

5.1.2 Handling high Doppler case

It is observed that DMRS needs to be enhanced for PC5-based V2V.

SC-FDM is used for V2V transmission in each physical channel.

Enhancement at least includes:

– Increase DMRS density to reduce time interval between DMRS sequences

– Enhance DMRS structure to increase frequency offset compensation range

Study at least the following DMRS structure:

– Reuse PUSCH DMRS

– Other options are not precluded, i.e.,

- PUSCH DMRS with Comb (similar as structure of SRS)
- New DMRS patterns spread over time and frequency, that may be frequency multiplexed with DFT-precoded data at least in some symbols
- Increased subcarrier spacing

– All options should solve any complexity and standardization impact including analysis of frequency synchronization accuracy

Working assumption is to increase DMRS density to 4 symbols per 1ms with reusing PUSCH DM RS sequence in each physical sidelink channel except for PSBCH.

- If RAN1 finds working assumption does not work, i.e. the performance cannot meet requirements for PC5 V2V at least including consideration on whether RAN1 working assumption of frequency offset is confirmed, the fir st priority should be given to DMRS structure with Comb (like SRS). There should be considerations on receiv er complexity when working assumption is confirmed.
- Location of DM RS is FFS. Options of DM RS location (counting from #0) for evaluation include the following for normal CP with 15 kHz subcarrier spacing (other options are not precluded):
    - Option 1: #2, #5, #8, #11 (Note: This is for regular spacing.)
    - Option 2: #1, #5, #8, #12 (Note: Reuse RS location of PUCCH format 2.)
    - Option 3: #2, #4, #9, #11 (Note: Frequency offset estimation first using {#2, #4} and {#9, #11})
    - Option 4: #3, #6, #7, #10 (Note: Frequency offset estimation first using {#6, #7})
- FFS the number and location of DMRS in PSBCH

5.1.3 Synchronization

GNSS or GNSS-equivalent is at the highest priority of synchronization source for time and frequency when the vehicle UE[1] directly receives GNSS or GNSS-equivalent with sufficient reliability and the UE does not detect any cell in any carrier.

eNB instructs vehicle UE to prioritize either eNB-based synchronization or GNSS or GNSS-equivalent at least when the eNB is in the carrier where the vehicle UE operates on PC5 V2V

Priority of GNSS or GNSS-equivalent for other cases needs further study

Priority of other synchronization source needs further study

- Scenarios with there is no eNB coverage and GNSS or GNSS-equivalent coverage need to be studied
    - RAN1 will not optimize only for this scenario
    - This scenario needs to be supported from the synchronization perspective

RAN1 assumes that eNBs may not always have GNSS or GNSS-equivalent

- Asynchronous network case should be supported.

Perspectives for further study:

- eNB assistant information, e.g.
    - Timing offset to UTC
    - TA or eNB location
    - others

SLSS and PSBCH transmission of UE is supported for PC5 based V2V.

- UE capability of SLSS transmission will be discussed later.
- Rel. 12/13 physical format of SLSS/PSBCH is the starting point.

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1 “Vehicle” UE in this clause indicates UE in PC5 V2V. This terminology is only used for discussion convenience.

        - FFS number and location of PSBCH DM RS
        - FFS PSSS root index, SLSS ID
    - Rel. 12/13 sync procedure (e.g., sync reference priority) is the starting point.
        - FFS PSBCH contents
        - “GNSS or GNSS-equivalent is at the highest priority of synchronization source for time and frequency when the vehicle UE directly receives GNSS or GNSS-equivalent with sufficient reliability and the U E does not detect any cell in any carrier.”
            - RAN1 needs to study the impact of this existing agreement on Uu operation.

The following sync procedure should be supported:

- Priority of synchronization source includes at least transmission timing reference.
- FFS whether there is any differentiation depending on whether eNB is synchronized to GNSS in the corresponding SLSS transmissions
- SLSS transmitted from out-coverage UE directly synchronized with GNSS or GNSS equivalent with sufficient reliability is differentiated from SLSS_net with in coverage indicator 1

- At least reuse priority order SLSS_net with in coverage indicator 1, SLSS_net with in coverage indicator 0, SLSS_oon
    - FFS: any new priorities can be defined if benefits are shown
    - FFS: Definition of SLSS_net, SLSS_oon
    - FFS: GNSS or GNSS equivalent priority
- Working assumption: Priority of SLSS transmitted from in-coverage UE directly synchronized with GNSS or GNSS equivalent with sufficient reliability is the same as that of SLSS_net with in coverage indicator 1
    - FFS: SLSS transmitted from in-coverage UE using GNSS or GNSS equivalent is configured by eNB
        - FFS: whether the configured SLSS uses the same configuration as Rel-12 D2D SLSS or not
    - FFS: SLSS transmitted from in-coverage UE using GNSS or GNSS equivalent is taken from SLSS_net with in coverage indicator 1
    - FFS: Periodicity of synchronization resource
- FFS: Criteria to select between signals received with the same priority (e.g., up to UE implementation)

5.2 Uu interface

5.2.1 Downlink enhancements

The following technical areas are identified as potential enhancements to Uu transport for V2V services:

- The use of both MBSFN and SC-PTM is allowed.
- Improvement of MBSFN/SC-PTM services on the basis of UE geographical location
    - It is assumed that the application/upper layer can provide the necessary location information for DL b roadcast. An AS layer mechanism is not needed to assist the application server to determine broadcast ing area.
- The need and solutions (if needed) to reduce MBSFN/SC-PTM latency can be considered. Possible enhancement

s primarily targeting control plane (but may be used for user plane) include:

- For MBSFN: shorter MCCH modification period, repetition period, and shorter MCCH scheduling pe riod (e.g. 10ms), and the use of pre-configured MRBs can be considered.
- For SC-PTM: shorter SC-MCCH modification period and shorter repetition period can be considered.

- Impact of supporting inter-operator deployments
  - A UE is allowed to receive downlink broadcast of other operator.
- Single TMGI across cell(s) or MBSFN area or per location TMGIs are possible.
  - For SC-PTM, a single G-RNTI can be common across cells(s) to reduce the delay caused by mobility;
  - TMGI and G-RNTI are configurable by the network.

For DL multicast/broadcast, RAN1 has observed performance benefit with the following enhancements:

- Dynamic scheduling for multicast/broadcast transmissions
  - I.e., PDCCH-based scheduling of TBs associated to a TMGI
- Semi-static scheduling for multicast/broadcast transmissions
- Use of DM-RS based transmission scheme from multiple TPs including reception for idle UEs
  - This does not imply introduction of any new TM
- DMRS-based single-cell multicast
- PDSCH transmitted from multiple TPs
- CRS based PDSCH/PDCCH transmitted from TP(s) that differ from the TP(s) transmitting the system information
- DMRS based PDSCH/EPDCCH transmitted from different TP(s)
- Use of normal CP
- HARQ feedback
- CSI feedback
- FFS MIMO features
- Note 1: Gain, complexity, and specification impact of each enhancement are expected to be different.
- Note 2: some enhancements may be possible without spec impact.
- Note 3: Network/UE complexity has not been studied in RAN1.
- Note 4: some enhancement(s) listed above may assume some level of inter-TP coordination, which does not necessarily result in spec changes
- Note 5: some enhancement(s) listed above may be based on contribution(s) from a limited number of company or companies

Some potential enhancements to DL multicast/broadcast listed above can be implemented by supporting the following features:

- Transmission using a single CP shorter than extended CP in the current MBSFN architecture for broadcast from multiple eNBs.

    - Baseline is normal CP, and this can be revisited considering the alignment of numerology being discussed in the eMBMS WI.
    - RAN1 assumes a certain level of network synchronization for multi-cell operations (RAN1 has no consensus on the need to specify additional network synchronization requirement for this). Such synchronization may be provided by the network implementation.
- SC-PTM using normal CP with legacy transmission mode of SC-PTM
- It is not intended to preclude the possibility of having HARQ and/or CSI feedback for SC-PTM and/or MBSFN transmissions by using the terminology "the current MBSFN architecture" and "legacy transmission mode of SC-PTM" above.

From RAN1 viewpoint, the following feature is beneficial:

- UE identifies which broadcast transmissions (e.g., TMGI) are relevant to it, e.g., depending on the position of the UE.

Using geo-information report from RRC_Connected UEs may be beneficial for downlink operation for V2X.

- RAN1 assumes that the UE geo-information reporting mechanism specified for PC5-based V2V can be reused for this purpose.

In the event that HARQ feedback for DL multicast/broadcast transmissions were to be introduced, at least in a single cell, two options are identified for HARQ feedback resource allocation:

- UE-common resource: Multiple UEs receiving the same DL multicast/broadcast transmission transmit HARQ feedback on the same resource.
- UE-specific resource: Different UEs receiving the same DL multicast/broadcast transmission transmit HARQ feedback on different resources.

5.2.2 Uplink enhancements

It is observed in 8.2.2 that E-UTRAN may not meet the latency requirement for Uu transport of V2V service when a long SR period (e.g. a longer than 10ms) is used. Thus, if Uu transport of V2V service is used, UEs should be configured with a shorter SR period such as 1ms or 10ms to meet the latency requirement on V2V service. However, it is also observed in 8.1.2 that configuring PUCCH SR resources with a short SR period such as 1ms or 10ms will increase undesirable uplink overhead. Such uplink overhead might be severe, particularly when a large number of vehicles exist in a cell e.g. in urban or when Uu resources are shared with other services.

In addition, it is observed that CAM message generation can be dynamic in terms of size, periodicity and timing. Such changes will result in misalignment between UL SPS timing and CAM timing. There may be some regularity in size and periodicity between different triggers.

To reduce uplink overhead, it is beneficial to use uplink Semi-Persistent Scheduling (SPS). In order to avoid added latency in the UE of waiting for SPS resources, the SPS period would have to be significantly shorter than the latency requirement of 100ms. For most CAM and DENM periods, this would result in a large amount of signaling overhead when (many) UEs need to signal to the eNB each time they do not need to use the resource. Thus, it is desirable to use a long SPS period e.g. between 100ms and 1 second for V2V service with potential enhancements described below. In addition, there is no way for the eNB to know the best SPS configuration for a given vehicle at any given time. Thus, the UE may need to assist the eNB to properly control UL SPS operation.

Accordingly, the following enhancements to uplink SPS are identified as potential solutions for V2V service:

- At least 100ms and 1s SPS periodicities should be included.
- Multiple SPS configurations with different parameters can be configured by eNB.
    - Which SPS configuration is being activated/deactivate can be signalled.
    - Two options are identified for multiple SPS configurations

        - Option 1: one active SPS at a time
        - Option 2: multiple SPS active at a time
    - SPS configuration and UE assistance information may be linked to one or more radio bearers.
- UE assistance at least on periodicity and/or timing can be provided to eNB.
    - UE assistance can be configured by eNB.
    - UL SPS configuration is decided by eNB.
    - Triggering of UE assistance can be discussed as part of stage 3 work.
- The UE can inform the network when SPS resources are not used, e.g. on control signaling

One or more of the enhancements listed above may be used simultaneously to support SPS transmissions.

Note that we will down-prioritize the idle mode case for Uu based V2V.

Hereinafter, the solutions above are briefly described.

5.2.1.1 Multiple SPS configurations

Multiple SPS configurations with different configuration parameters can be configured by eNB in order to address message characteristics of V2V service e.g. CAM, DENM and BSM, and support both V2V service and VoIP service.

For example, CAM messages are periodically generated with dynamically changed periodicity between 1 second and 100ms. When CAM message generation time changes e.g. from 1 second to 100ms, SPS resource allocation with one periodicity e.g. 1 second does not match the changed CAM message generation period. Considering dynamic CAM message generation in time, the eNB can provide the UE with multiple SPS configurations covering different message periodicities. In this case, it may be sufficient that only one SPS configuration is active at a time.

In addition, BSM messages are periodically transmitted with 100ms periodicity. However, the actual message size can vary in time. If the SPS resource grant cannot accommodate a BSM message due to size variation, the UE may request dynamic UL resource allocation. To avoid significant use of dynamic UL resource allocation, the eNB may provide the UE with mulitple SPS configurations covering different message sizes. In this case, it may be sufficient that only one SPS configuration is active at a time.

Meanwhile, a vehicular UE may generate both CAM and DENM messages from time to time. The vehicular UE may also make a phone call e.g a voice call while generating messages for V2V service. Considering that CAM, DENM and a voice call have different characteristics, the eNB can provide the UE with multiple SPS configurations e.g. for CAM, DENM and voice call. In this case, it can be further discussed in Stage 3 whether or not multiple SPS configurations can be active at a time.

5.2.1.2 UE assistance for SPS

After the eNB activates SPS by PDCCH addressed by SPS C-RNTI, SPS resource grants occurs periodically. Since the eNB cannot know when the UE generates the messages, the SPS resource grants allocated by eNB may not exactly match the actual message generation time. Such mismatch between the actual message generation time and SPS resource grant will cause lateny in V2V service.

Considering the strigent V2V requirement on latency of 100ms, the UE can assist the eNB to ensure SPS grants are alligned with periodic message transmission by triggering an SPS reactivation with timing change. As illustrated in Figure 5-1, when the UE detects a significant mismatch between the actual message generation time and SPS resource grant, the UE sends assistance information about the timing change to the eNB. Upon receiving the assistance information, the eNB may re-initiate SPS to change timing of SPS resource allocation. It needs to be further discussed in Stage 3 how assistance information is signalled to the eNB as well as related triggering conditions.

In addition, if the UE can detect change of message periodicity, the UE may send assistance information including the changed message peridocity to the eNB. This assistance information can help the eNB activate a SPS configuration when mulitple SPS configurations with different periodicities are configured by the eNB.

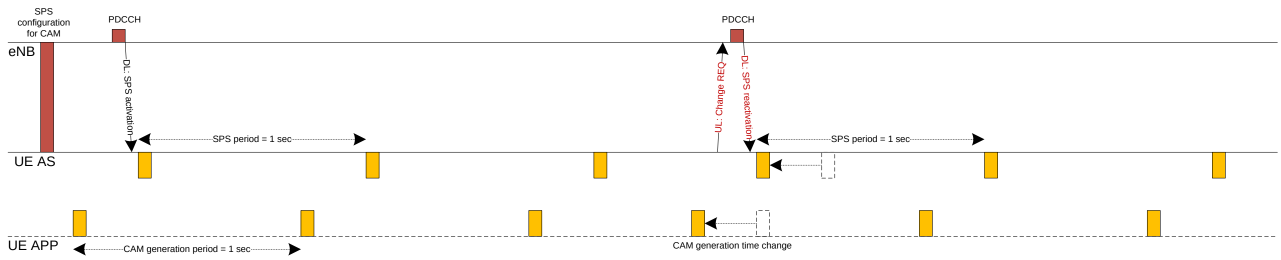


Figure 5-1: Example of UE assistance for SPS with timing change of CAM transmissions in UL

5.2.1.3 UE informs eNB when SPS resources are not used

It is assumed that the UE and the eNB do not exactly know the CAM message generation time and it is difficult for the eNB to allocate SPS resource grants which exactly match with dynamic CAM message generation. Thus, the UE may not use a certain SPS resource grant for transmission. To avoid SPS resource grant wastage in V2V transmissions, the UE may inform the eNB when SPS resources are not used.

Note that from RAN2 point of view, for UL SPS, it is not necessary to send an indication to the eNB that an SPS grant will not be used. Therefore, the working assumption on “the UE can indicate to the eNB that it does not intend to transmit data before a transmission associated to an SPS configuration” is not needed.

6 Technical support for V2I/N

6.1 PC5 interface

- At least the following aspects need to be discussed for PC5-based V2I
  - Evaluation results on potential V2V performance degradation if “I” transmits in the same carrier and if V2I performance can meet requirements to conclude observation on performances
  - Feasibility of reusing PC5-based V2V to V2I
    - To conclude which case needs further enhancements over PC5-based V2V
  - Note that V2I includes both directions

The working assumption is that side-link physical layer design used for V2V is used for V2I if side-link is used for V2I.

It is agreed that a common pool is used for V2X and I2X.

The design will be based on broadcast mechanism. No optimization is expected for unicast case in this release.

6.2 Uu interface

The working assumption is that DL physical design used for V2V is used for I2V if DL physical design is used for I2V, and UL physical design used for V2V is used for V2I if UL physical design is used for V2I.

7 Technical support for V2P

Note that P2V (i.e., pedestrian UE transmission and vehicle UE reception) is prioritized over V2P (i.e., vehicle UE transmission and pedestrian UE reception) in the study.

7.1 PC5 interface

- At least the following aspects need to be discussed for PC5-based V2P
  - Evaluation results on potential V2V performance degradation if "P" transmits in the same carrier and if V2P performance can meet requirements to conclude observation on performances
  - Feasibility of reusing PC5-based V2V to V2P
    - To conclude which case needs further enhancements over PC5-based V2V
  - Power consumption for transmission or reception of "P"
  - Complexity of the UE supporting transmission of "P"
  - Note that V2P includes both directions

For the purpose for P-UE TX to reduce the power consumption and UE complexity, at least the followings are beneficial:

- Random resource selection.
- FFS Sensing operation during a limited time

Random resource selection for P2V transmission minimizes power consumption for PC5-based V2P service and does not require UE to receive on PC5 carrier. Also, random resource selection is able to meet the requirement of V2P services including the PRR performance requirement.

Compared to random resource selection, sensing operation during a limited time can improve the PRR performance with additional power consumption and the need for UE reception on PC5 carrier.

Design used for PC5-V2V is used for P-UE reception of V-UE transmissions.

It needs to be further discussed in Stage 3 whether a separate pool is needed for P2X or the common pool used for V2X and I2X can be also used for P2X.

The design will be based on broadcast mechanism. No optimization is expected for unicast case in this release.

7.2 Uu interface

8 Architecture and high level procedures for V2X

8.1 Local Breakout for V2X

An RSU may terminate the V2X packets, or forward the V2X packets to other entities. This is done in the V2X application layer of the RSU. The handling of V2X packet is transparent to the eNB. It is also transparent to the eNB regarding whether the RSU has a local V2X server.

If the P-GW is close to the eNB, the backhaul delay can be significantly reduced; local breakout seems beneficial in order to better fulfill the stringent latency requirements of V2X services. This enables a more local termination of V2X traffic instead of traversing the EPC.

The above may also provide additional flexibility for the location of the local E-UTRAN V2X server: i.e. behind a L-GW (stand-alone or co-located with the eNB), or in the eNB itself. In fact, if SIPTO@LN is assumed to be deployed, it may be fully possible to leave this to the specific deployment. We could see the following use cases:

1. *V2X server, connected through SIPTO@LN with stand-alone GW* – Such a V2X server could e.g. process data from an array of local sensors / cameras, to distribute to all locally connected vehicle UEs. Connectivity would be provided to all local eNBs identified by the same LHN ID. By appropriately planning the LHN IDs with the V2X service areas, V2X services can be provided to the appropriate location in the most optimal way. Thanks to the characteristics of SIPTO@LN with stand-alone GW, the connection to the server would always be maintained at vehicle UE mobility within the LHN.
2. *V2X server, connected through SIPTO@LN with co-located L-GW* – Same as above, but the connection is routed through a L-GW co-located in each eNB. In this case, however, the connection of the vehicle UE to the server is taken down during mobility and set up again through the L-GW in the target eNB after handover has completed.
3. *V2X server co-located in the eNB*– In this case all required functionality is implemented in the eNB. An example of this could be e.g. a physical road-side box containing the sensors (i.e. terminating all traffic locally) and the RSU, which also handles the relevant connection to the vehicle UEs. This can be seen as “collapsing” all the above logical nodes into one physical node, even together with the V2X server.

When using SIPTO@LN with stand-alone GW, the interface between the stand-alone GW and the V2X Server is based on SGi. When using SIPTO@LN with co-located L-GW, the interface between the co-located L-GW and the V2X Server may be an internal interface or SGi.

Given that V2X functionality provides road safety services to moving vehicle UEs, option 1 (SIPTO@LN with stand-alone GW) seems to be more appropriate with respect to the other options, since it is the only one that maintains the data connection through handovers.

Some further observations can be made.

- Current SIPTO@LN does not support dedicated bearers: only a single (default) bearer is supported, mainly due to the fact that there is no interface between the GW and the PCRF. The QoS of such a bearer, therefore, needs to meet the V2X service requirements.
- For SIPTO@LN with standalone GW, IP data session continuity can only be maintained if both source eNB and target eNB belong to the same Local Home Network. If the UE has no other PDN connection and it moves out of the Local Home Network, the MME detaches the UE.

On the first observation, it depends on SA2 whether using the newly defined QCI for a default bearer is enough, or introducing support for dedicated bearers is needed.

8.2 MBMS for V2X

8.2.1 Delivery of V2x Messages via MBMS

In Scenario 2, V2x messages need to be broadcasted in the vicinity of the originating vehicle UE. The originating vehicle UE sends its V2X messages over the application layer to the V2x server. The messages include information on the vehicle location (long, lat). The vehicle UE may also provide cell-related information.

In a similar but simpler scenario, V2x messages are generated e.g. in the V2x server or in road sensors, and distributed to vehicle UEs. In this case, there is no need to take into account the position of the vehicle UE for the distribution, and the messages can be delivered using MBSFN or SC-PTM (or even unicast if feasible). This latter case seems less challenging.

8.2.1.1 Architecture

For the delivery of V2X messages, the architecture shown below can be used.

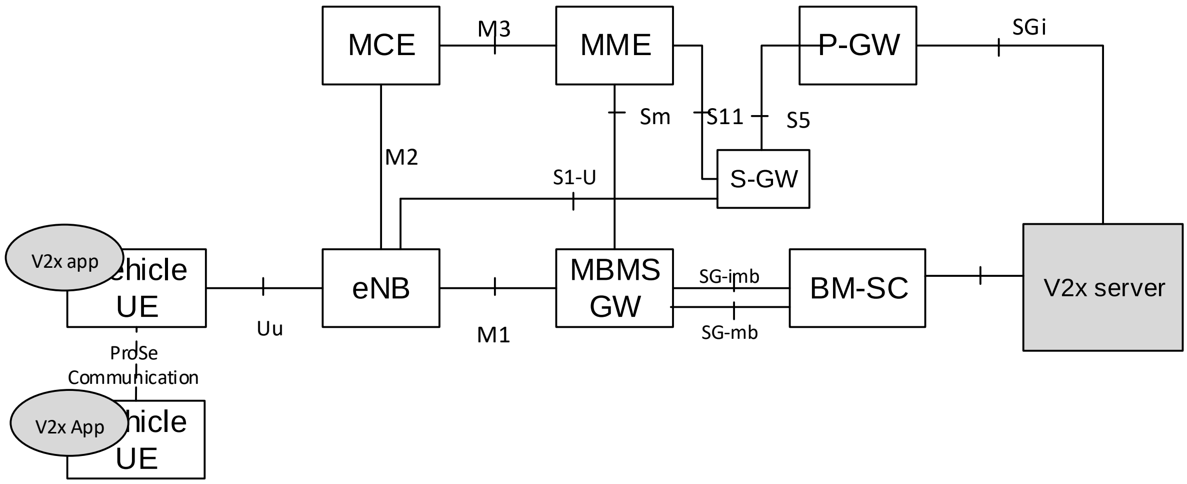


Figure 8-1: Architecture for V2x message delivery through MBMS.

8.2.1.2 Signalling Flow

A high-level signaling flow is shown in 错误!未找到引用源。 below.

- The mapping between TMGIs and V2x services should be known at the vehicle UEs (e. g. by configuration, or by dedicated communication, etc.);
- The V2x server should request and pre-establish the appropriate MBMS bearer(s) to the appropriate eNBs; the MBMS session (MBSFN or SC-PTM) is started in the appropriate area/cell(s);
- The originating vehicle UE sends the V2x messages, including (lat, lon), and possibly cell-related information, to the V2x server over Uu uplink;
- The V2x server determines the target broadcast area considering the positions of the vehicle UEs, possibly taking into account any cell-related information transmitted by the vehicle UEs;
- V2x traffic is sent to the vehicle UEs in the appropriate area.

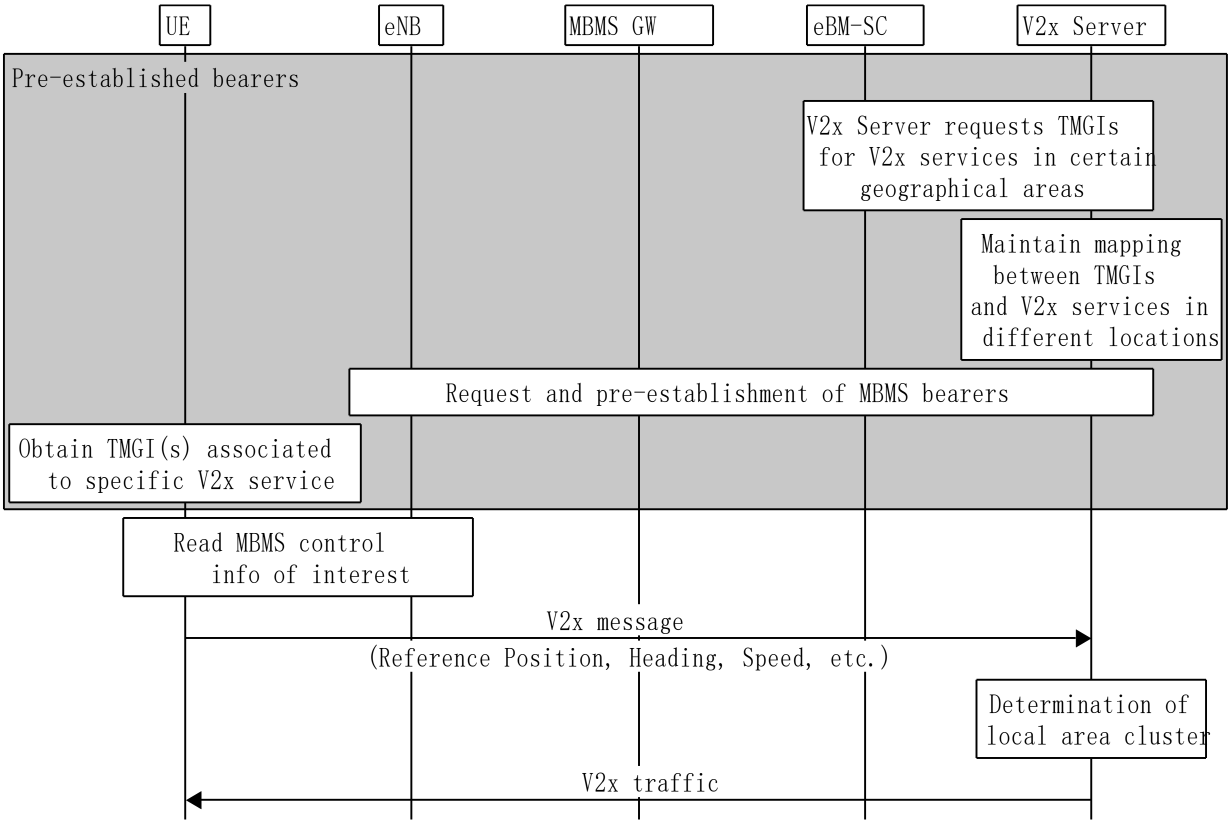


Figure 8-2: V2x message distribution through pre-established MBMS bearers.

8.2.2 Support of small and variable areas in V2X

In V2V/V2I/V2P service, in most use cases, the V2X message may be broadcast in a small range of areas. Such areas may change due to the movement of the vehicle UE. For example, a vehicle UE may periodically broadcast a message (CAM) including the vehicle dynamic status information (e.g. location, speed and direction information) to its surrounding vehicles while moving, to assist safety operations. It is expected that the surrounding vehicles within 300-500 meters range from the vehicle UE should be able to receive the V2X message. The small and variable areas in V2X could be managed via MBSFN and/or SC-PTM.

8.2.2.1 Issues

In order to support small and variable broadcast areas in V2X, following issues should be investigated:

- Issue 1: How to decide the V2X broadcast area. The assumption is the V2X server can make the decision, e.g. based on the V2X message received from the transmission UE. The broadcast area for a specific V2X message may cover one or more cells.

- Issue 2: How to transmit different V2X messages in different broadcast areas, especially in overlapping areas. Different V2X messages may be broadcasted on the same MBMS bearer in different broadcast areas. When the MBMS Service Areas for V2X broadcast overlap, current MBMS cannot support transmitting different content in the MBMS bearers with same TMGI in those overlapping V2X broadcast areas.

8.2.2.2 Solutions

8.2.2.2.1 Solution for solving issue 1

The V2x server receives the location of the transmitting V2x UE, and taking into account the V2x UE location decides on the most appropriate broadcast area in which to start the MBMS session.

This solution relies on the V2x server implementation, thus its details are out of scope of this TR.

8.2.2.2.2 Solutions for solving issue 2

For solving issue 2, the following two solutions are given:

8.2.2.2.2.1 Single TMGI based solution

Option 1: Solution with new ID to differentiate the flows with same TMGI

For Uu based V2V as an example, when vehicles upload their V2V message to the V2X server, as the message is expected to be received by the surrounding vehicles within 300-500 meters range of the source vehicle, only one small group of cells (may only include one cell or a list of cells) covering the transmission range needs to broadcast the V2X messages. As shown in Figure 8-3, the Cell Group1 only needs to broadcast the information uploaded by the red and green vehicles, Cell Group2 needs to broadcast the information uploaded by the red, green and yellow vehicles, etc.

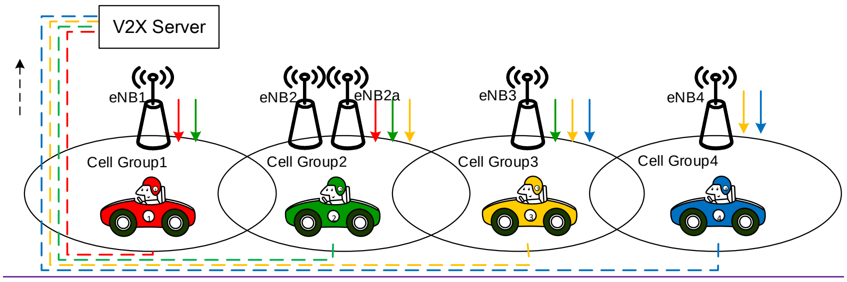


Figure 8-3: Uu based V2V transmission and Reception

The existing flow id allows the network to provide different data in different areas using same TMGI, but it does not support the overlapping area scenario.

For V2X, in order to provide different data in overlapping areas using same TMGI, an x id is introduced in this solution, it is provided from the V2X server and forward by the BM-SC, MBMS-GW and MME towards the E-UTRAN together with a list of cells, to identify different data content with the same TMGI, and this applies to both different areas and overlapping areas.

As shown in Figure below, after establishing multiple MBMS sessions with different x ids of the same TMGI, the V2X server provides the data for each x id to the network, and MBMS-GW sends the corresponding data of different x id bearer to different multicast IP address. Note that the indicated broadcast area for these sessions could be overlapped.

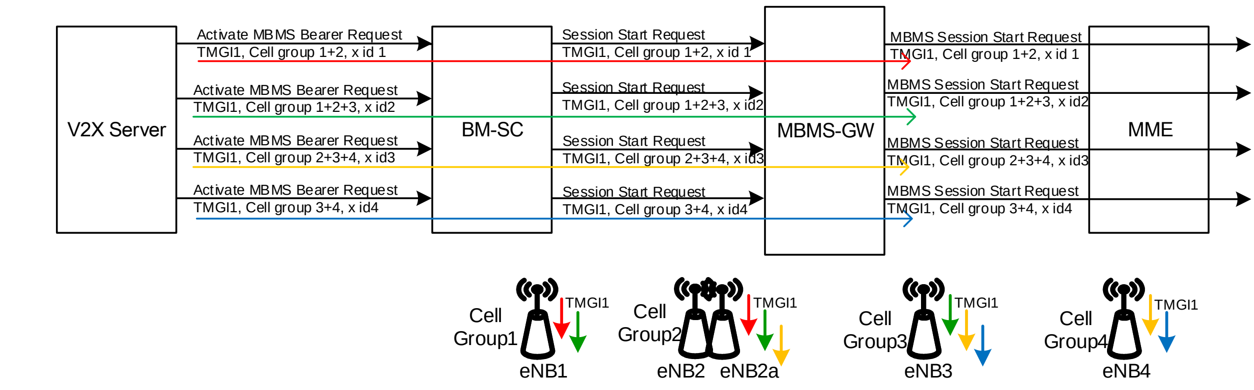


Figure 8-4

Upon receiving multiple MBMS Session Start Requests of the same TMGI but different x id, the eNB joins multiple multicast addresses and get the corresponding data. Note that the eNB needs to distinguish multiple x ids for the same TMGI, combines the data of different x ids, and provides in the Uu interface using the same TMGI.

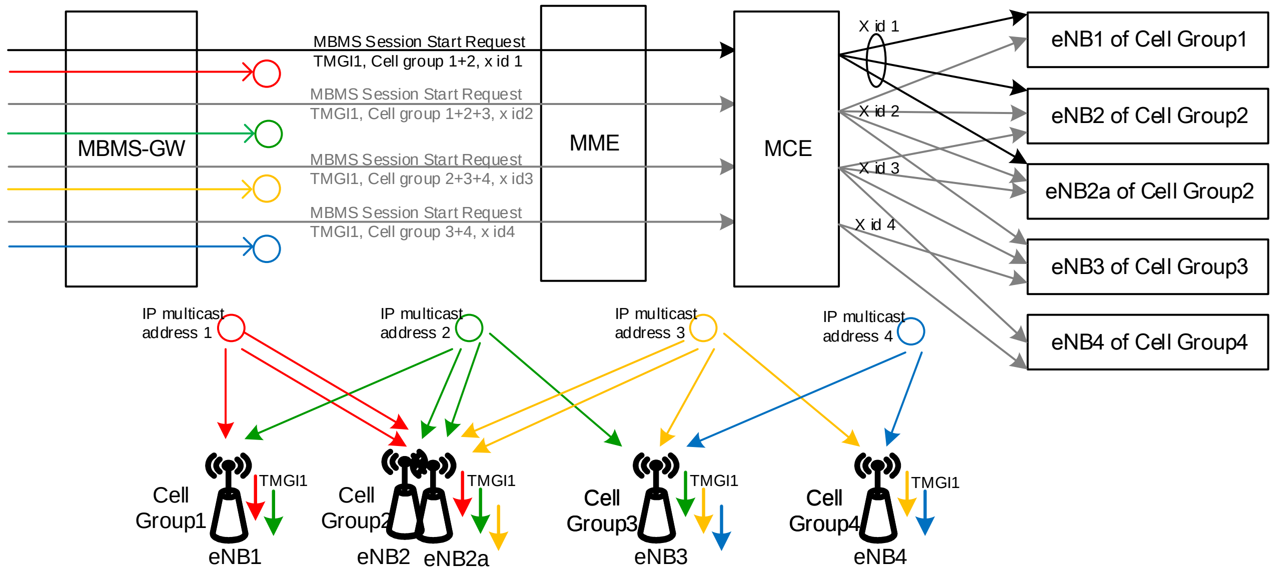


Figure 8-5

In this solution, the UEs will only need to listen to the same TMGI in the network for the same V2X service, and the complex TMGI management is avoided.

Option 2: Solution to use non-overlapped MBMS Service Areas

Considering the transmission range for V2X packet is very small, e.g. 320m in freeway scenario (TR 22.885), operator may configure small, non-overlapped MBMS Service Areas for V2X, e.g. a MBMS Service Area only consists of two eNBs. In the related MBMS Service Areas, it is possible to use the same TMGI for a specific type of V2X packets. It is possible to reuse the existing location dependent content transfer for the MBMS user service to distribute the different set of V2X packets in different broadcast areas.

Option 3: User plane enhancement solution

In this solution, the V2X server pre-establishes an MBMS bearer with a specific TMGI for a type of V2X service in a very large MBMS broadcast area. The BM-SC decodes the V2X message and adds the broadcast area information in the SYNC header. For example, the BM-SC decodes the CAM1 and generates the MBMS packet 1 (i.e. SYNC PDU 1) including the CAM 1 received from the transmitting vehicle UE(s), and the V2X broadcast area {cell 1,2,5,6,11,12,13} in the SYCN header, etc., as shown in Figure 8-6. Then the BM-SC sends the generated MBMS packets via the pre-established MBMS bearer to its downstream entities (i.e. MBMS GW, eNB). When the MBMS packets arrive at the eNB, the eNB decodes the new SYNC header to know the V2X broadcast area, and decides whether to broadcast MBMS packets or not. This solution impact the BM-SC, the eNB and the SYNC protocol.

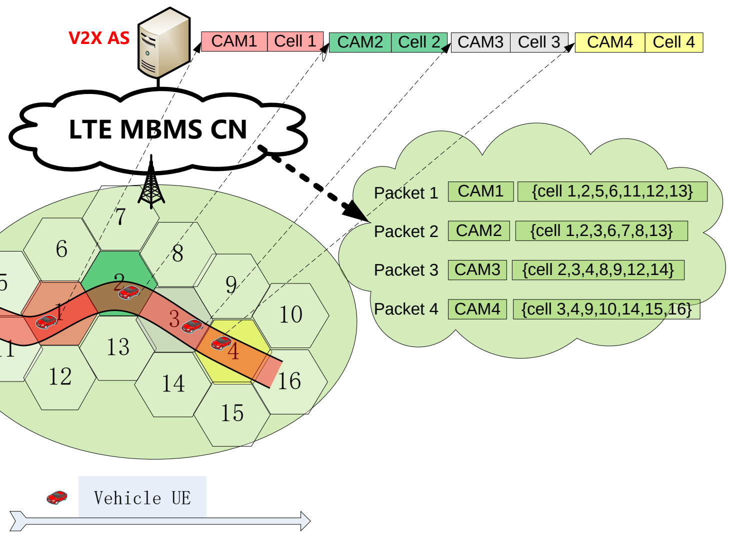


Figure 8-6: Example of user plane enhancement solution

8.2.2.2.2.2 Multiple TMGIs based solution

This solution applies different TMGIs to the MBMS Service Areas when there is overlap, in order to be able to transmit different V2X messages in different overlapped broadcast areas.

8.2.2.2.2.3 Solution evaluation

In order to better understand the pros and cons on the two solutions above, the comparison table is summarized in table 8-1.

Table 8-1: Comparison table between single TMGI and multiple TMGIs based solutions

	Single TMGI based solution			**Multiple TMGIs based solution**
	Option 1	**Option 2**	**Option 3**	
UE capability requirement	No new requirement The number of TMGIs to be received by the UE within a cell is one at a time.	No new requirement The number of TMGIs to be received by the UE within a cell is one at a time.	No new requirement The number of TMGIs to be received by the UE within a cell is one at a time.	Medium Reception of more than one MBMS service in parallel at a time is required.
UE's USD Reception	Once per local MBMS area When the UE moves from one cell to another within the same local MBMS area, it does not need to receive the related TMGI list because all cells including a local MBMS area use the same TMGI.	Once per local MBMS area When the UE moves from one cell to another within the same local MBMS area, it does not need to receive the related TMGI list because all cells including a local MBMS area use the same TMGI.	Once per local MBMS area When the UE moves from one cell to another within the same local MBMS area, it does not need to receive the related TMGI list because all cells including a local MBMS area use the same TMGI.	Several times When the UE moves from one cell to another within the same local MBMS area, the new USD needs to be received for the related TMGI.
How to support overlapping areas and the impacts to MCE and eNB	MCE impacts: procedure update to support new ID eNB impacts: - procedure update to	No impacts to eNB and MCE	No impact to MCE. eNB impact: eNB decodes the new SYNC header to know the V2X broadcast	No impacts to eNB and MCE

	support new ID - eNB shall not reject the session start request if there is an overlap for the flows		area, and decides whether to broadcast MBMS packets or not.	
The amount of signaling for MBMS Session Start procedure	Proportional to the number of small areas The different flows of the same TMGI should also be triggered by different session start procedures.	Proportional to the number of small areas The different flows of the same TMGI should also be triggered by different session start procedures.	Relatively less amount of signaling required: only one session start procedure is needed in the local area	Proportional to the number of small areas Multiple session start procedures should be triggered for different TMGIs

The selection of a solution depends on network deployment.

8.2.3 Localized MBMS

In current MBMS system shown in Figure 8-1, the BM-SC, MBMS-GW and MME are located in the Core Network. The backhaul delay between the BM-SC and the eNB is non-negligible when calculating the end-to-end delay, especially when MBMS is used to delivery downlink V2X packets in the V2X system. To minimize the latency, it may be necessary to consider the following options:

- To move the MBMS CN functions (e.g. BM-SC, MBMS-GW) close to the eNB, or even collocated in the eNB.
- To move the User Plane of MBMS CN functions (BM-SC, MBMS-GW) close to the eNB, or even collocated in the eNB.

8.2.3.1 Deployment Options of Localized MBMS based on implementation

In order to minimize V2x latency, different deployment options can be considered. None of the options below seems to have any specification impact.

8.2.3.1.1 Localized V2x Server and MBMS – Co-Located with the eNB

In this case *the V2x server, BM-SC, and MBMS GW are all co-located in the eNB*. V2x messages are delivered in the cells served by the hosting eNB: this option seems particularly appropriate in conjunction with the distributed MCE architecture, i.e. in case the hosting eNB also includes its own MCE. All UP interfaces are internal, so V2x latency is the minimum possible. This option is shown in Figure 8-7 below.

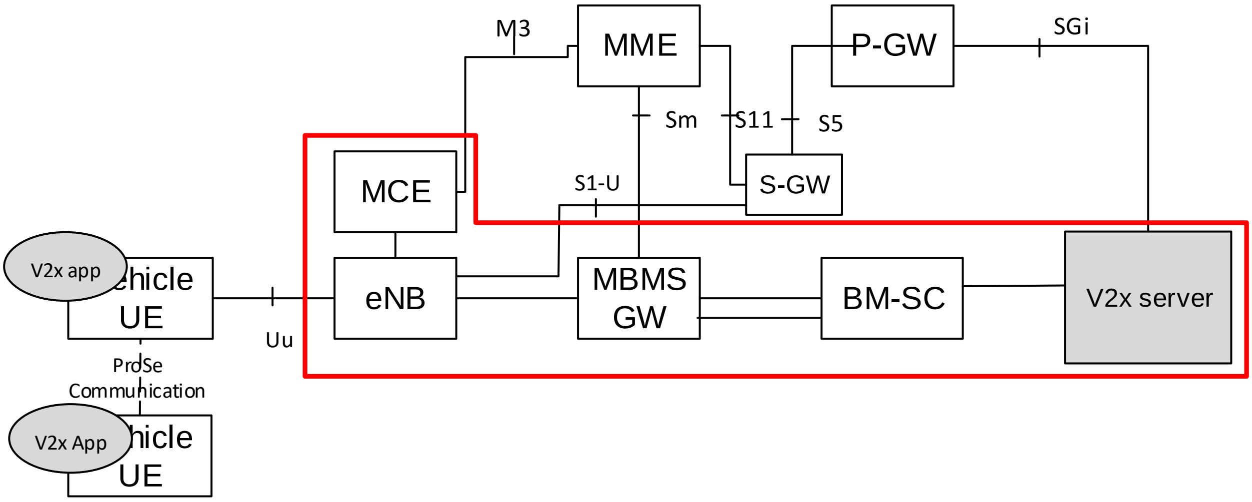


Figure 8-7: Localized V2x server and MBMS, co-located with the eNB.

8.2.3.1.2 Localized V2x Server and MBMS – Not co-Located with the eNB

In this case *the V2x Server, BM-SC, and MBMS GW are all co-located, but* not *in the eNB*. This physical node may forward V2x traffic toward several eNBs, and this seems to be an advantage over the previous option. This option is shown in Figure 8-8 below.

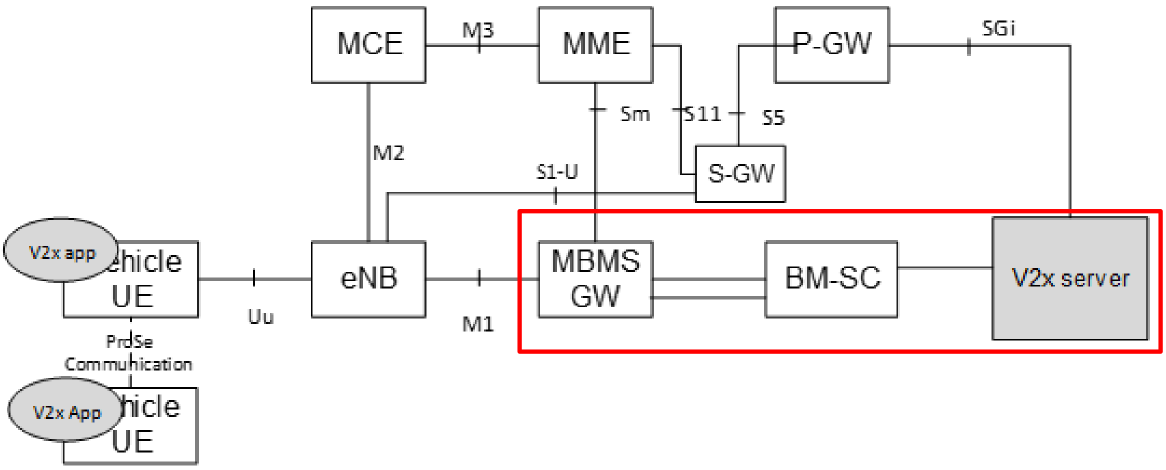


Figure 8-8: Localized V2x server and MBMS, not co-located with the eNB.

8.2.3.1.3 Issues for Localized MBMS based on implementation

In the options above, operator deploys Localized MBMS including the functions of BM-SC and MBMS-GW in the RAN for V2X service. The non-V2X MBMS service still uses the BM-SC and MBMS-GW in the Core Network. The Localized MBMS has the same functions as the macro BM-SC/MBMS-GW, e.g. service announcement function, session and transmission function, IP multicast distribution, etc, as defined in TS 23.246.

A UE may connect to multiple BM-SCs for authentication, service announcement, etc. However, this is different to multiple BM-SCs deployment in the current standard, which is used for load balancing purpose (TS 33.246). The current standard does not support the UE to use the local BM-SC for V2X MBMS service, and macro BM-SC for non-V2X MBMS services at the same time. The Service announcement, bootstrapping, MBMS user service registration, etc. uses the BM-SC server resolved by the FQDN. According to TS 23.003,

- The service announcement FQDN is defined as "mbmsbs.mnc.mcc.pub.3gppnetwork.org".
- The BM-SC server FQDN is defined as mbms.mnc.mcc.3gppnetwork.org.

These FQDNs are unique per PLMN ID. It is not possible for UE to know both local BM-SC and macro BM-SC via the FQDN, so the UE cannot connect to both local BM-SC and macro BM-SC for service announcement, bootstrapping, MBMS User Service Registration, etc. In addition, the UE or the UICC only stores one set of keys per PLMN. It also has some issues for network sharing.

- The RAN operator may not have a PLMN ID, so it is a big challenge for the RAN operator to deploy a LME (e.g. allocate TMGI with PLMN ID).
- For a Gateway Core Network (GWCN) network sharing, the CN operator may need to open a new interface in order for the Local MBMS EPC to connect to the BSF/HSS for MBMS User Service registration. The CN operator may have less control on e.g. how to map the V2X service QoS to MBMS service QoS, how to set ARP, etc.

The FQDN issue described above may be addressed by the V2X server redirecting the UE to the most appropriate local BM-SC, given that the V2X server is always aware of the UE location. For inter-PLMN cases, if the serving ECGI information is available, the V2x server can also take into account the serving PLMN ID contained in the ECGI when redirecting the UE to the appropriate BM-SC. The change of local BM-SC may add additional delay to the MBMS reception by the UEs. This may impact current SA/CT specifications.

8.2.3.2 Options of Localized User Plane MBMS CN functions

8.2.3.2.1 Localized V2x Server and LME – Co-Located with the eNB

In this case *the V2x server, Local MBMS Entity (LME) which includes User Plane of MBMS CN functions (BM-SC and MBMS GW) are all co-located in the eNB*. The V2x messages are delivered in the cells served by the hosting eNB. All User Plane interfaces are internal, so V2x latency is the minimum possible. This option is shown in Figure 8-9 below.

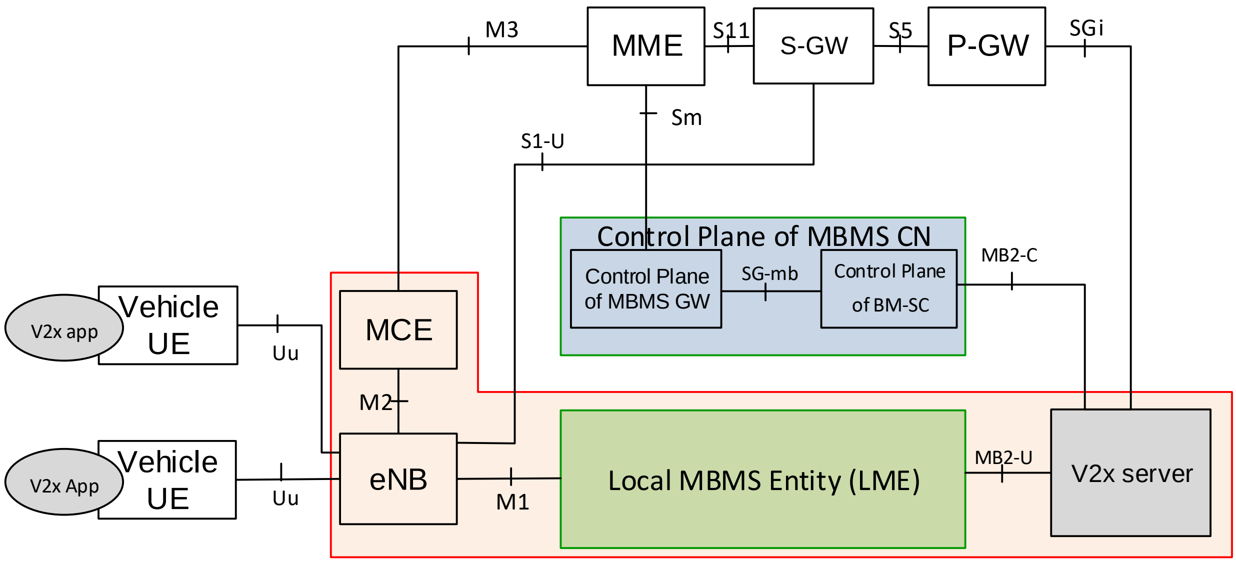


Figure 8-9: Localized V2x server and UP MBMS CN, co-located with the eNB.

The function split of Control Plane of MBMS CN and the LME, if and how to define an interface between them, as well as pros/cons of this solution, are subject to SA2 discussion.

8.2.3.2.2 Localized V2x Server and LME – Not co-Located with the eNB

In this case *the V2x Server, Local MBMS Entity (LME) which includes User Plane of MBMS CN functions (BM-SC and MBMS GW) are all co-located, but* not *in the eNB*. The V2X messages could be delivered in the cells served by several eNBs, and this seems to be an advantage over the previous option. This option is shown in Figure 8-10 below.

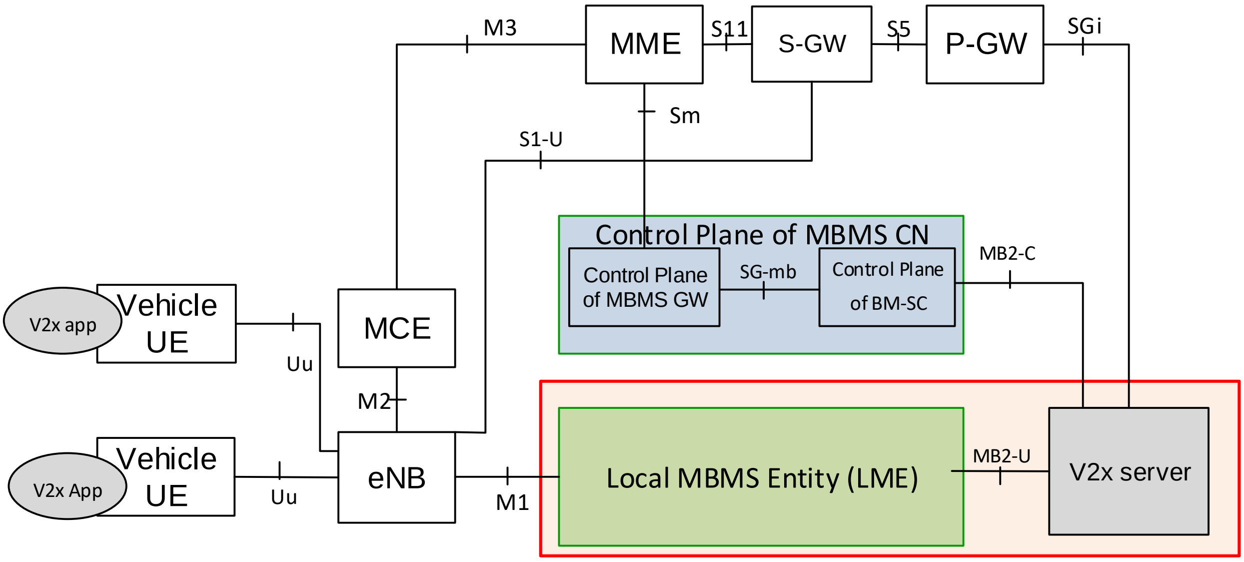


Figure 8-10: Localized V2x server and UP MBMS CN, not co-located with the eNB.

The function split of Control Plane of MBMS CN and the LME, if and how to define an interface between them, as well as pros/cons of this solution, are subject to SA2 discussion.

8.2.3.3 V2x Server Deployment Options

All the options presented in the previous sections only present one deployment option for the V2x server. Where to deploy the V2x server (e.g. centralized and/or localized) is out of the scope of this TR.

8.3 Multiple Operator support in V2X

The following scenarios need to be supported for V2X:

- Usage Scenario 1: Only Operator A have eNBs in a specific area. Operator A's eNB are shared with Operator B for all services including V2X.

  Operator A's eNB indicates the support for Operator B's PLMN ID in the SIB.

- Usage Scenario 2: Only Operator A own the dedicated V2X spectrum in a specific area. Operator A's eNB are shared with Operator B only for V2X service.

  The V2X service may be provided via a PLMN ID dedicated for V2X service.

- Usage Scenario 3: Both Operator A and B have eNBs in a specific area. V2X server distribute the V2X msg to both operators' network.

  One option is the V2X server connects to both operator's network, just like a normal service provider providing services to UEs from multiple operators. Or the UE listen to the MBMS of other operator(s).

9 Evaluation results

9.1 Capacity analysis

9.1.1 PC5-based V2V

This clause summarizes the evaluation results of PC5 transport for V2V services in the scenarios defined in Table A. 1.5-1. Table 9.1-1 shows the average PRR in the range (n*20, (n+1)*20) m from transmitters where n=15, 7, 2 for freeway case, urban case with 60 km/h vehicle speed, and urban case with 15 km/h vehicle speed, respectively. 100 msec latency for message delivery is targeted in evaluations. Details of the evaluation assumptions and results of each source can be found in Annex B.

Table 9.1-1: Average PRR for PC5-based V2V (a=n*20 m, b=(n+1)*20 m)

Description	Scenario#1 (n=15)	Scenario#2 (n=15)	Scenario#3 (n=7)	Scenario#4 (n=2)	Scenario#5 (n=2)
Source 1	0.9190	0.7810	0.5995	0.7196	0.9441
Source 2	0.7524	0.6663	0.4886	0.5709	–
Source 3	0.9733	0.9671	0.5423	–	–
Source 4	0.8544	0.7730	0.5584	0.8163	–
Source 5	0.7811	0.7004	0.4789	0.8012	–
Source 6	0.9385	0.6348	0.6024	0.7966	0.9846
Source 7	0.8903	0.5634	0.5736	0.7826	0.9785
Source 8	0.8364	0.5921	0.4856	0.7668	–
Source 9	0.8917	0.6560	0.6737	0.8369	–
Source 10	0.9798	0.8927	0.7042	0.9273	–
Source 11	0.9099	0.8416	0.7284	0.8842	–
Source 12	0.7020	0.3115	0.4397	0.6182	0.9066

The following observations are made from the performance results under the agreed evaluation scenarios:

- In freeway cases, the performance of PC5 interface with enhancements exceeds or approaches 80% average PRR at 320m range.
- In urban cases with 15 km/h, the performance of PC5 interface with enhancements achieves average PRR 90% at 50m range.
- In urban cases with 60 km/h speed, the performance of PC5 interface with enhancements achieves about 60% average PRR at 150m range.
- It is noted that evaluations in RAN1 used the geographical distance between vehicles, and this can be shorter than the actual travelling distance between vehicles which may be more relevant to the definition of the effective range in [3]. Average PRR would be increased if the actual travelling distance is used.
- It is noted that some of the enhancements identified in Clause 5.1.1 are not simulated in some sources.

- It is noted that no system level calibration was performed.

9.1.2 Uu-based V2V

This clause summarizes the evaluation results of Uu transport for V2V services.

The following observations are made based on the results of the latency analysis in section 9.2.1 and the results of the capacity analysis in [17] for the agreed evaluation scenarios:

- Short SR/SPS periods (i.e. 1 and 10ms SR period, 10 and 40ms SPS period) increase UL overhead for V2V, pa rticularly in Urban case with 15 km/h and in Freeway case with 70km/h where the number of vehicles is high.
    - With dynamic scheduling UL capacity can be met with 1ms SR, if 100% UL resources of a 10 Mhz ca rrier are available for V2V services.
    - For SPS with 10ms the UL capacity cannot be met and for 40ms it is very challenging to meet.Given t hat we cannot assume 100% of the resources are available for V2V services, some UL enhancements can be considered.
- If our assumption of 100ms periodicity is confirmed and if somehow SPS can be aligned with the packet gener ation, then an SPS of 100ms can be used.
- It is challenging to meet the DL capacity requirement for the Urban cases. We will study DL enhancements to improve the DL capacity.
    - Unicast cannot meet the capacity requirements for Urban cases and Freeway cases option 1.
    - We will focus on improvements to DL broadcast mechanisms.
- Message drop rates increase for UEs with high speed due to high handover failure rates particularly in Freeway cases with 140 km/h, and consequently overall PRR performance is degraded.

Table 9.1-2 shows the average PRR in the range (n*20, (n+1)*20) m from transmitters where n=15, 7, 2 for freeway case, urban case with 60 km/h vehicle speed, and urban case with 15 km/h vehicle speed, respectively. 100 msec latency for message delivery is targeted in evaluations. Details of the evaluation assumptions and results of each source can be found in Annex C.

Table 9.1-2: Average PRR for Uu-based V2V (a=n*20 m, b=(n+1)*20 m)

Description	Scenario#2 (n=15)	Scenario#3 (n=7)	Scenario#4 (n=2)
Source 1	0.9811	–	–
Source 2	–	0.9661	–
Source 3	–	0.8958	–
Source 4	–	0.9261	–
Source 5	–	0.9037	–
Source 6	–	0.8913	–
Source 7	–	0.9014	–
Source 8	–	0.8885	–
Source 9	–	0.8235	–

Source 10	–	0.6793	–
Source 11	0.9540	–	–
Source 12	0.9760	–	–
Source 13	1.0000	–	–
Source 14	–	0.9200	–
Source 15	–	0.9470	–
Source 16	–	0.7110	–
Source 17	–	0.9730	–
Source 18	–	0.7380	–
Source 19	–	–	0.9040
Source 20	–	–	0.3650
Source 21	–	–	0.5260
Source 22	–	–	0.6560
Source 23	–	–	0.7980
Source 24	–	0.7007	–
Source 25	–	0.6860	–
Source 26	–	0.8382	–
Source 27	–	0.7262	–
Source 28	–	0.9320	–
Source 29	–	–	0.6778
Source 30	–	–	0.5279
Source 31	–	–	0.3162
Source 32	–	–	0.6506
Source 33	–	–	0.4228

The following observations are made from the performance results under the agreed evaluation scenarios:

- In freeway cases with 70 km/h, the performance of Uu interface with enhancements achieves about average PRR 98% at 320m range.
- In urban cases with 60 km/h, the performance of Uu interface with enhancements achieves about average PRR 84% at 150m range.
- In urban cases with 15 km/h, the performance of Uu interface with enhancements achieves about average PRR 58% at 50m range.

9.1.3 Uu-based V2I/N

This clause summarizes the evaluation results of Uu transport for V2I/N services. Table 9.1-3 shows the average PRR in the range (n*20, (n+1)*20) m from transmitters where n=3, 1 for urban case with 60 km/h vehicle speed and urban case with 15 km/h vehicle speed, respectively. V2I/I2V traffic model 1 in A.1.5 is assumed and 100 msec latency for message delivery is targeted in evaluations. Details of the evaluation assumptions and results of each source can be found in Annex D.

Table 9.1-3: Average PRR for Uu-based V2I/N (a=n*20 m, b=(n+1)*20 m)

Description	Scenario#3 (n=3)	Scenario#4 (n=1)
Source 1	0.9911	–
Source 2	0.9200	–
Source 3	–	0.9500
Source 4	0.7229	–
Source 5	–	0.6512

The following observations are made from the performance results under the agreed evaluation scenarios:

- In urban cases with 60 km/h, the performance of Uu interface with enhancements achieves about average PRR 88% at 75m range.
- In urban cases with 15 km/h, the performance of Uu interface with enhancements achieves about average PRR 80% at 25m range.

9.1.4 PC5-based V2I/N

This clause summarizes the evaluation results of PC5 transport for V2I/N services. Table 9.1.4-1 shows the average PRR for V-UE RX of UE type RSU TX with V-UE TX in the range (n*20, (n+1)*20) m from transmitters where n=7, 3, 1 for freeway case, urban case with 60 km/h vehicle speed, and urban case with 15 km/h vehicle speed, respectively. In Table 9.1.4-1, Table 9.1.4-2 and Table 9.1.4-3, V2I/I2V traffic model 1 in A.1.5 is assumed and 100 msec latency for message delivery is targeted in evaluations. Details of the evaluation assumptions and results of each source can be found in Annex E.

Table 9.1.4-1: Average PRR for V-UE RX of UE type RSU TX with V-UE TX (a=n*20 m, b=(n+1)*20 m)

Description	Scenario#2 (n=7)	Scenario#3 (n=3)	Scenario#4 (n=1)
Source 1	–	0.9106	–
Source 2	–	–	0.8589
Source 3	0.9815	–	–
Source 4	–	0.9899	–
Source 5	–	1.0000	–
Source 6	–	0.9682	–
Source 7	–	–	1.0000
Source 8	–	–	0.9904
Source 9	0.9693	–	–

Source 10	–	–	–
Source 11	–	0.9951	–
Source 12	–	–	–
Source 13	0.9367	–	–
Source 14	–	0.9708	–
Source 15	–	–	0.9378

The following observations are made from the performance results for V-UE RX of UE type RSU TX with V-UE TX under the agreed evaluation scenarios:

- In freeway cases with 70 km/h, the performance of PC5 interface with enhancements achieves about average PRR 96% at 160m range.
- In urban cases with 60 km/h, the performance of PC5 interface with enhancements achieves about average PRR 97% at 75m range.
- In urban cases with 15 km/h, the performance of PC5 interface with enhancements achieves about average PRR 95% at 25m range.

Table 9.1.4-2 shows the average PRR for UE type RSU RX of V-UE TX with UE type RSU TX in the range (n*20, (n+1)*20) m from transmitters where n=7, 3, 1 for freeway case, urban case with 60 km/h vehicle speed, and urban case with 15 km/h vehicle speed, respectively.

Table 9.1.4-2: Average PRR for UE type RSU RX of V-UE TX with UE type RSU TX (a=n*20 m, b=(n+1)*20 m)

Description	Scenario#2 (n=7)	Scenario#3 (n=3)	Scenario#4 (n=1)
Source 1	–	0.7988	–
Source 2	–	–	0.7406
Source 3	0.9788	–	–
Source 4	–	0.9596	–
Source 5	–	0.9868	–
Source 6	–	0.9844	–
Source 7	–	–	0.9678
Source 8	–	–	0.9692
Source 9	0.9447	–	–
Source 10	–	–	–
Source 11	–	0.9777	–
Source 12	–	–	–
Source 13	0.8781	–	–
Source 14	–	0.8991	–

Source 15	−	−	0.8349

The following observations are made from the performance results for UE type RSU RX of V-UE TX with UE type RSU TX under the agreed evaluation scenarios:

- In freeway cases with 70 km/h, the performance of PC5 interface with enhancements achieves about average PRR 93% at 160m range.
- In urban cases with 60 km/h, the performance of PC5 interface with enhancements achieves about average PRR 93% at 75m range.
- In urban cases with 15 km/h, the performance of PC5 interface with enhancements achieves about average PRR 88% at 25m range.

Table 9.1.4-3 shows the change of average PRR of PC5-based V2V caused by UE type RSU TX in the range (n*20, (n+1)*20) m from transmitters where n=15, 7, 2 for freeway case, urban case with 60 km/h vehicle speed, and urban case with 15 km/h vehicle speed, respectively.

Table 9.1.4-3: Change of average PRR of PC5-based V2V caused by UE type RSU TX (a=n*20 m, b=(n+1)*20 m)

Description	Scenario#2 (n=15)	Scenario#3 (n=7)	Scenario#4 (n=2)
Source 1	−	−	−
Source 2	−	−	−
Source 3	-2.8443 %	−	−
Source 4	−	-0.7668 %	−
Source 5	−	-2.3387 %	−
Source 6	−	-0.4459 %	−
Source 7	−	−	-2.7262 %
Source 8	−	−	1.0131 %
Source 9	-9.0141 %	−	−
Source 10	−	−	−
Source 11	−	-1.1765 %	−
Source 12	−	−	−
Source 13	-77.7614 %	−	−
Source 14	−	-1.5032 %	−
Source 15	−	−	0.0124 %

9.1.5 PC5-based V2P

This clause summarizes the evaluation results of PC5 transport for V2P services. Table 9.1.5-1 shows the average PRR for V-UE RX of P-UE TX with V-UE TX in the range (n*20, (n+1)*20) m from transmitters where n=3, 1 for urban case with 60 km/h vehicle speed and urban case with 15 km/h vehicle speed, respectively. In Table 9.1.5-1, Table 9.1.5-

2 and Table 9.1.5-3, 100 msec latency for message delivery is targeted in evaluations. Details of the evaluation assumptions and results of each source can be found in Annex F.

Table 9.1.5-1: Average PRR for V-UE RX of P-UE TX with V-UE TX (a=n*20 m, b=(n+1)*20 m)

Description	Scenario#3 (n=3)	Scenario#4 (n=1)
Source 1	0.9269	–
Source 2	–	–
Source 3	–	0.7265
Source 4	0.9232	–
Source 5	0.8942	–
Source 6	0.7698	–
Source 7	–	–
Source 8	–	0.9312
Source 9	–	0.7823
Source 10	–	–
Source 11	0.8148	–
Source 12	–	0.9079
Source 13	0.9106	–
Source 14	0.8457	–
Source 15	0.9394	–
Source 16	–	0.8674
Source 17	–	0.9850

The following observations are made from the performance results for V-UE RX of P-UE TX with V-UE TX under the agreed evaluation scenarios:

- In urban cases with 60 km/h, the performance of PC5 interface with enhancements achieves about average PRR 88% at 75m range.
- In urban cases with 15 km/h, the performance of PC5 interface with enhancements achieves about average PRR 87% at 25m range.

Table 9.1.5-2 shows the average PRR for P-UE RX of V-UE TX with P-UE TX in the range (n*20, (n+1)*20) m from transmitters where n=3, 1 for urban case with 60 km/h vehicle speed and urban case with 15 km/h vehicle speed, respectively.

Table 9.1.5-2: Average PRR for P-UE RX of V-UE TX with P-UE TX (a=n*20 m, b=(n+1)*20 m)

Description	Scenario#3	Scenario#4

	(n=3)	(n=1)
Source 1	0.9496	–
Source 2	0.7503	–
Source 3	–	0.8584
Source 4	0.8799	–
Source 5	0.9312	–
Source 6	0.9224	–
Source 7	0.9345	–
Source 8	–	0.9733
Source 9	–	0.9701
Source 10	–	0.9747
Source 11	–	–
Source 12	–	–
Source 13	0.8484	–
Source 14	0.8249	–
Source 15	0.8621	–
Source 16	–	0.8554
Source 17	–	0.8923

The following observations are made from the performance results for P-UE RX of V-UE TX with P-UE TX under the agreed evaluation scenarios:

- In urban cases with 60 km/h, the performance of PC5 interface with enhancements achieves about average PRR 88% at 75m range.
- In urban cases with 15 km/h, the performance of PC5 interface with enhancements achieves about average PRR 92% at 25m range.

Table 9.1.5-3 shows the change of average PRR of PC5-based V2V caused by P-UE TX in the range (n*20, (n+1)*20) m from transmitters where n=7, 2 for urban case with 60 km/h vehicle speed and urban case with 15 km/h vehicle speed, respectively.

Table 9.1.5-3: Change of average PRR of PC5-based V2V caused by P-UE TX (a=n*20 m, b=(n+1)*20 m)

Description	Scenario#3 (n=7)	Scenario#4 (n=2)
Source 1	-1.3100 %	–
Source 2	-29.0493 %	–
Source 3	–	–
Source 4	-0.6885 %	–

Source 5	-0.7138 %	–
Source 6	-2.2875 %	–
Source 7	0.1587 %	–
Source 8	–	0.2003 %
Source 9	–	-0.1339 %
Source 10	–	0.4898 %
Source 11	-1.5494 %	–
Source 12	–	-1.2627 %
Source 13	-3.9554 %	–
Source 14	-1.0289 %	–
Source 15	-5.3181 %	–
Source 16	–	1.6102 %
Source 17	–	-3.5228 %

9.2 Latency Analysis

9.2.1 Evaluation of overall latency

In this section, the overall latency results of scenarios listed in section 4 using different parameter sets are provided.

For Scenario 2, the analysis of control plane latency due to mobility is provided in this section.

List of parameter sets for evaluation

Family of parameter set 1:

Configuration	Set 1a	Set 1b	Set 1c	Set 1d
UL scheduling scheme	Dynamic with BSR	Dynamic w/o BSR	Dynamic with BSR	Dynamic with BSR
SR period	1	1	1	1
SPS period	N/A	N/A	N/A	N/A
MCH scheduling period	40	40	40	40
SCPTM scheduling period	10	10	10	1
SL scheduling scheme	Mode2	Mode2	Mode1	Mode2

Family of parameter set 2:

Configuration	Set 12	Set 2b	Set 2c	Set 2d
UL scheduling scheme	Dynamic with BSR	Dynamic w/o BSR	Dynamic with BSR	Dynamic with BSR
SR period	10	10	10	10
SPS period	N/A	N/A	N/A	N/A
MCH scheduling period	40	40	40	40
SCPTM scheduling period	10	10	10	1
SL scheduling scheme	Mode2	Mode2	Mode1	Mode2

Family of parameter set 3:

Configuration	Set 3a	Set 3b	Set 3c
UL scheduling scheme	SPS	SPS	SPS
SR period	10	10	10
SPS period	10	10	10
MCH scheduling period	40	40	40
SCPTM scheduling period	10	10	1
SL scheduling scheme	Mode2	Mode1	Mode2

Family of parameter set 4:

Configuration	Set 4a	Set 4b	Set 4c
UL scheduling scheme	SPS	SPS	SPS
SR period	10	10	10
SPS period	40	40	40
MCH scheduling period	40	40	40
SCPTM scheduling period	10	10	1
SL scheduling scheme	Mode2	Mode1	Mode2

Family of parameter set 5:

Configuration	Set 5a	Set 5b	Set 5c
UL scheduling scheme	SPS	SPS	SPS
SR period	10	10	10
SPS period	10	10	10
MCH scheduling period	80	80	80
SCPTM scheduling period	10	10	1
SL scheduling scheme	Mode2	Mode1	Mode2

The overall latency results for each parameter set are presented below.

Parameter set 1a:

Parameter set:

Configuration	**Values/policy**
UL scheduling scheme	Dynamic with BSR
SR period	1
SPS period	N/A
MCH scheduling period	40
SCPTM scheduling period	10
SL scheduling scheme	mode2

Overall latency results:

Scenario#	**Mandatory+optional**		**Only mandatory**	
	Mean	Max	Mean	Max
S1: SL	130.1	164.1	52.5	86
S2-1: UL→DL_uc	311.6	472.1	47.6	48.1
S2-2: UL→DL_mbms	117.8	138.3	67.8	88.3

S2-3: UL→DL_scptm	102.8	108.3	52.8	58.3
S3A-1: SL→UL→DL_uc	444.7	639.2	103.1	137.1
S3A-2: SL→UL→DL_mbms	250.9	305.4	123.3	177.3
S3A-3: SL→UL→DL_scptm	235.9	275.4	108.3	147.3
S3B-1: UL→DL_uc→SL	394.7	589.2	103.1	137.1
S3B-2: UL→DL_mbms→SL	250.9	305.4	123.3	177.3
S3B-3: UL→DL_scptm→SL	235.9	275.4	108.3	147.3

Parameter set 1b:

Parameter set:

Configuration	Values/policy
UL scheduling scheme	Dynamic without BSR
SR period	1
SPS period	N/A
MCH scheduling period	40
SCPTM scheduling period	10
SL scheduling scheme	mode2

Overall latency results:

Scenario#	Mandatory+optional		Only mandatory	
	Mean	Max	Mean	Max
S1: SL	130.1	164.1	52.5	86
S2-1: UL→DL_uc	303.6	464.1	39.6	40.1
S2-2: UL→DL_mbms	109.8	130.3	59.8	80.3
S2-3: UL→DL_scptm	94.8	100.3	44.8	50.3
S3A-1: SL→UL→DL_uc	436.7	631.2	95.1	129.1
S3A-2: SL→UL→DL_mbms	242.9	297.4	115.3	169.3
S3A-3: SL→UL→DL_scptm	227.9	267.4	100.3	139.3
S3B-1: UL→DL_uc→SL	386.7	581.2	95.1	129.1
S3B-2: UL→DL_mbms→SL	242.9	297.4	115.3	169.3
S3B-3: UL→DL_scptm→SL	227.9	267.4	100.3	139.3

Parameter set 1c:

Parameter set:

Configuration	Values/policy
UL scheduling scheme	Dynamic with BSR
SR period	1
SPS period	N/A
MCH scheduling period	40
SCPTM scheduling period	10
SL scheduling scheme	mode1

Overall latency results:

Scenario#	Mandatory+optional	Only mandatory

	Mean	Max	Mean	Max
S1: SL	138.6	173.1	61	95
S2-1: UL→DL_uc	311.6	472.1	47.6	48.1
S2-2: UL→DL_mbms	117.8	138.3	67.8	88.3
S2-3: UL→DL_scptm	102.8	108.3	52.8	58.3
S3A-1: SL→UL→DL_uc	453.2	648.2	111.6	146.1
S3A-2: SL→UL→DL_mbms	259.4	314.4	131.8	186.3
S3A-3: SL→UL→DL_scptm	244.4	284.4	116.8	156.3
S3B-1: UL→DL_uc→SL	403.2	598.2	111.6	146.1
S3B-2: UL→DL_mbms→SL	259.4	314.4	131.8	186.3
S3B-3: UL→DL_scptm→SL	244.4	284.4	116.8	156.3

Parameter set 1d

Parameter set:

Configuration	Values/policy
UL scheduling scheme	Dynamic with BSR
SR period	1
SPS period	N/A
MCH scheduling period	40
SCPTM scheduling period	1
SL scheduling scheme	mode2

Overall latency results:

Scenario#	**Mandatory+optional**		**Only mandatory**	
	Mean	Max	Mean	Max
S1: SL	130.1	164.1	52.5	86
S2-1: UL→DL_uc	311.6	472.1	47.6	48.1
S2-2: UL→DL_mbms	117.8	138.3	67.8	88.3
S2-3: UL→DL_scptm	98.3	99.3	48.3	49.3
S3A-1: SL→UL→DL_uc	444.7	639.2	103.1	137.1
S3A-2: SL→UL→DL_mbms	250.9	305.4	123.3	177.3
S3A-3: SL→UL→DL_scptm	231.4	266.4	103.8	138.3
S3B-1: UL→DL_uc→SL	394.7	589.2	103.1	137.1
S3B-2: UL→DL_mbms→SL	250.9	305.4	123.3	177.3
S3B-3: UL→DL_scptm→SL	231.4	266.4	103.8	138.3

Parameter set 2a:

Parameter set:

Configuration	**Values/policy**
UL scheduling scheme	Dynamic with BSR
SR period	10
SPS period	N/A
MCH scheduling period	40
SCPTM scheduling period	10
SL scheduling scheme	mode2

Overall latency results:

Scenario#	Mandatory+optional		Only mandatory	
	Mean	Max	Mean	Max
S1: SL	134.6	173.1	52.5	86
S2-1: UL→DL_uc	316.1	481.1	52.1	57.1
S2-2: UL→DL_mbms	122.3	147.3	72.3	97.3
S2-3: UL→DL_scptm	107.3	117.3	57.3	67.3
S3A-1: SL→UL→DL_uc	453.7	657.2	107.6	146.1
S3A-2: SL→UL→DL_mbms	259.9	323.4	127.8	186.3
S3A-3: SL→UL→DL_scptm	244.9	293.4	112.8	156.3
S3B-1: UL→DL_uc→SL	403.7	607.2	107.6	146.1
S3B-2: UL→DL_mbms→SL	259.9	323.4	127.8	186.3
S3B-3: UL→DL_scptm→SL	244.9	293.4	112.8	156.3

Parameter set 2b:

Parameter set:

Configuration	Values/policy
UL scheduling scheme	Dynamic without BSR
SR period	10
SPS period	N/A
MCH scheduling period	40
SCPTM scheduling period	10
SL scheduling scheme	mode2

Overall latency results:

Scenario#	Mandatory+optional		Only mandatory	
	Mean	Max	Mean	Max
S1: SL	134.6	173.1	52.5	86
S2-1: UL→DL_uc	308.1	473.1	44.1	49.1
S2-2: UL→DL_mbms	114.3	139.3	64.3	89.3
S2-3: UL→DL_scptm	99.3	109.3	49.3	59.3
S3A-1: SL→UL→DL_uc	445.7	649.2	99.6	138.1
S3A-2: SL→UL→DL_mbms	251.9	315.4	119.8	178.3
S3A-3: SL→UL→DL_scptm	236.9	285.4	104.8	148.3
S3B-1: UL→DL_uc→SL	395.7	599.2	99.6	138.1
S3B-2: UL→DL_mbms→SL	251.9	315.4	119.8	178.3
S3B-3: UL→DL_scptm→SL	236.9	285.4	104.8	148.3

Parameter set 2c:

Parameter set:

Configuration	Values/policy
UL scheduling scheme	Dynamic with BSR

SR period	10
SPS period	N/A
MCH scheduling period	40
SCPTM scheduling period	10
SL scheduling scheme	mode1

Overall latency results:

Scenario#	Mandatory+optional		Only mandatory	
	Mean	Max	Mean	Max
S1: SL	147.6	191.1	65.5	104
S2-1: UL→DL_uc	316.1	481.1	52.1	57.1
S2-2: UL→DL_mbms	122.3	147.3	72.3	97.3
S2-3: UL→DL_scptm	107.3	117.3	57.3	67.3
S3A-1: SL→UL→DL_uc	466.7	675.2	120.6	164.1
S3A-2: SL→UL→DL_mbms	272.9	341.4	140.8	204.3
S3A-3: SL→UL→DL_scptm	257.9	311.4	125.8	174.3
S3B-1: UL→DL_uc→SL	416.7	625.2	120.6	164.1
S3B-2: UL→DL_mbms→SL	272.9	341.4	140.8	204.3
S3B-3: UL→DL_scptm→SL	257.9	311.4	125.8	174.3

Parameter set 2d

Parameter set:

Configuration	Values/policy
UL scheduling scheme	Dynamic with BSR
SR period	10
SPS period	N/A
MCH scheduling period	40
SCPTM scheduling period	1
SL scheduling scheme	Mode2

Overall latency results:

Scenario#	Mandatory+optional		Only mandatory	
	Mean	Max	Mean	Max
S1: SL	134.6	173.1	52.5	86
S2-1: UL→DL_uc	316.1	481.1	52.1	57.1
S2-2: UL→DL_mbms	122.3	147.3	72.3	97.3
S2-3: UL→DL_scptm	102.8	108.3	52.8	58.3
S3A-1: SL→UL→DL_uc	453.7	657.2	107.6	146.1
S3A-2: SL→UL→DL_mbms	259.9	323.4	127.8	186.3
S3A-3: SL→UL→DL_scptm	240.4	284.4	108.3	147.3
S3B-1: UL→DL_uc→SL	403.7	607.2	107.6	146.1
S3B-2: UL→DL_mbms→SL	259.9	323.4	127.8	186.3
S3B-3: UL→DL_scptm→SL	240.4	284.4	108.3	147.3

Parameter set 3a:

Parameter set:

Configuration	Values/policy
UL scheduling scheme	SPS
SR period	10
SPS period	10
MCH scheduling period	40
SCPTM scheduling period	10
SL scheduling scheme	Mode2

Overall latency results:

Scenario#	Mandatory+optional		Only mandatory	
	Mean	Max	Mean	Max
S1: SL	134.6	173.1	52.5	86
S2-1: UL→DL_uc	299.8	464.8	35.8	40.8
S2-2: UL→DL_mbms	106	131	56	81
S2-3: UL→DL_scptm	91	101	41	51
S3A-1: SL→UL→DL_uc	437.4	640.9	91.3	129.8
S3A-2: SL→UL→DL_mbms	243.6	307.1	111.5	170
S3A-3: SL→UL→DL_scptm	228.6	277.1	96.5	140
S3B-1: UL→DL_uc→SL	387.4	590.9	91.3	129.8
S3B-2: UL→DL_mbms→SL	243.6	307.1	111.5	170
S3B-3: UL→DL_scptm→SL	228.6	277.1	96.5	140

Parameter set 3b:

Parameter set:

Configuration	Values/policy
UL scheduling scheme	SPS
SR period	10
SPS period	40
MCH scheduling period	40
SCPTM scheduling period	10
SL scheduling scheme	mode1

Overall latency results:

Scenario#	Mandatory+optional		Only mandatory	
	Mean	Max	Mean	Max
S1: SL	147.6	191.1	65.5	104
S2-1: UL→DL_uc	299.8	464.8	35.8	40.8
S2-2: UL→DL_mbms	106	131	56	81
S2-3: UL→DL_scptm	91	101	41	51
S3A-1: SL→UL→DL_uc	450.4	658.9	104.3	147.8
S3A-2: SL→UL→DL_mbms	256.6	325.1	124.5	188
S3A-3: SL→UL→DL_scptm	241.6	295.1	109.5	158
S3B-1: UL→DL_uc→SL	400.4	608.9	104.3	147.8
S3B-2: UL→DL_mbms→SL	256.6	325.1	124.5	188
S3B-3: UL→DL_scptm→SL	241.6	295.1	109.5	158

Parameter set 3c

Parameter set:

Configuration	Values/policy
UL scheduling scheme	SPS
SR period	10
SPS period	10
MCH scheduling period	40
SCPTM scheduling period	1
SL scheduling scheme	Mode2

Overall latency results:

Scenario#	Mandatory+optional		Only mandatory	
	Mean	Max	Mean	Max
S1: SL	134.6	173.1	52.5	86
S2-1: UL→DL_uc	299.8	464.8	35.8	40.8
S2-2: UL→DL_mbms	106	131	56	81
S2-3: UL→DL_scptm	86.5	92	36.5	42
S3A-1: SL→UL→DL_uc	437.4	640.9	91.3	129.8
S3A-2: SL→UL→DL_mbms	243.6	307.1	111.5	170
S3A-3: SL→UL→DL_scptm	224.1	268.1	92	131
S3B-1: UL→DL_uc→SL	387.4	590.9	91.3	129.8
S3B-2: UL→DL_mbms→SL	243.6	307.1	111.5	170
S3B-3: UL→DL_scptm→SL	224.1	268.1	92	131

Parameter set 4a

Parameter set:

Configuration	Values/policy
UL scheduling scheme	SPS
SR period	10
SPS period	40
MCH scheduling period	40
SCPTM scheduling period	10
SL scheduling scheme	Mode2

Overall latency results:

Scenario#	Mandatory+optional		Only mandatory	
	Mean	Max	Mean	Max
S1: SL	134.6	173.1	52.5	86
S2-1: UL→DL_uc	314.8	494.8	50.8	70.8
S2-2: UL→DL_mbms	121	161	71	111
S2-3: UL→DL_scptm	106	131	56	81
S3A-1: SL→UL→DL_uc	452.4	670.9	106.3	159.8

S3A-2: SL→UL→DL_mbms	258.6	337.1	126.5	200
S3A-3: SL→UL→DL_scptm	243.6	307.1	111.5	170
S3B-1: UL→DL_uc→SL	402.4	620.9	106.3	159.8
S3B-2: UL→DL_mbms→SL	258.6	337.1	126.5	200
S3B-3: UL→DL_scptm→SL	243.6	307.1	111.5	170

Parameter set 4b

Parameter set:

Configuration	Values/policy
UL scheduling scheme	SPS
SR period	10
SPS period	40
MCH scheduling period	40
SCPTM scheduling period	10
SL scheduling scheme	mode1

Overall latency results:

Scenario#	**Mandatory+optional**		**Only mandatory**	
	Mean	Max	Mean	Max
S1: SL	147.6	191.1	65.5	104
S2-1: UL→DL_uc	314.8	494.8	50.8	70.8
S2-2: UL→DL_mbms	121	161	71	111
S2-3: UL→DL_scptm	106	131	56	81
S3A-1: SL→UL→DL_uc	465.4	688.9	119.3	177.8
S3A-2: SL→UL→DL_mbms	271.6	355.1	139.5	218
S3A-3: SL→UL→DL_scptm	256.6	325.1	124.5	188
S3B-1: UL→DL_uc→SL	415.4	638.9	119.3	177.8
S3B-2: UL→DL_mbms→SL	271.6	355.1	139.5	218
S3B-3: UL→DL_scptm→SL	256.6	325.1	124.5	188

Parameter set 4c

Parameter set:

Configuration	Values/policy
UL scheduling scheme	SPS
SR period	10
SPS period	40
MCH scheduling period	40
SCPTM scheduling period	1
SL scheduling scheme	Mode2

Overall latency results:

Scenario#	**Mandatory+optional**		**Only mandatory**	
	Mean	Max	Mean	Max
S1: SL	134.6	173.1	52.5	86
S2-1: UL→DL_uc	314.8	494.8	50.8	70.8
S2-2: UL→DL_mbms	121	161	71	111

S2-3: UL→DL_scptm	101.5	122	51.5	72
S3A-1: SL→UL→DL_uc	452.4	670.9	106.3	159.8
S3A-2: SL→UL→DL_mbms	258.6	337.1	126.5	200
S3A-3: SL→UL→DL_scptm	239.1	298.1	107	161
S3B-1: UL→DL_uc→SL	402.4	620.9	106.3	159.8
S3B-2: UL→DL_mbms→SL	258.6	337.1	126.5	200
S3B-3: UL→DL_scptm→SL	239.1	298.1	107	161

Parameter set 5a

Parameter set:

Configuration	Values/policy
UL scheduling scheme	SPS
SR period	10
SPS period	80
MCH scheduling period	40
SCPTM scheduling period	10
SL scheduling scheme	Mode2

Overall latency results:

Scenario#	**Mandatory+optional**		**Only mandatory**	
	Mean	Max	Mean	Max
S1: SL	134.6	173.1	52.5	86
S2-1: UL→DL_uc	334.8	534.8	70.8	110.8
S2-2: UL→DL_mbms	141	201	91	151
S2-3: UL→DL_scptm	126	171	76	121
S3A-1: SL→UL→DL_uc	472.4	710.9	126.3	199.8
S3A-2: SL→UL→DL_mbms	278.6	377.1	146.5	240
S3A-3: SL→UL→DL_scptm	263.6	347.1	131.5	210
S3B-1: UL→DL_uc→SL	422.4	660.9	126.3	199.8
S3B-2: UL→DL_mbms→SL	278.6	377.1	146.5	240
S3B-3: UL→DL_scptm→SL	263.6	347.1	131.5	210

Parameter set 5b

Parameter set:

Configuration	Values/policy
UL scheduling scheme	SPS
SR period	10
SPS period	80
MCH scheduling period	40
SCPTM scheduling period	10
SL scheduling scheme	Mode1

Overall latency results:

Scenario#	**Mandatory+optional**	**Only mandatory**

	Mean	Max	Mean	Max
S1: SL	147.6	191.1	65.5	104
S2-1: UL→DL_uc	334.8	534.8	70.8	110.8
S2-2: UL→DL_mbms	141	201	91	151
S2-3: UL→DL_scptm	126	171	76	121
S3A-1: SL→UL→DL_uc	485.4	728.9	139.3	217.8
S3A-2: SL→UL→DL_mbms	291.6	395.1	159.5	258
S3A-3: SL→UL→DL_scptm	276.6	365.1	144.5	228
S3B-1: UL→DL_uc→SL	435.4	678.9	139.3	217.8
S3B-2: UL→DL_mbms→SL	291.6	395.1	159.5	258
S3B-3: UL→DL_scptm→SL	276.6	365.1	144.5	228

Parameter set 5c

Parameter set:

Configuration	Values/policy
UL scheduling scheme	SPS
SR period	10
SPS period	80
MCH scheduling period	40
SCPTM scheduling period	1
SL scheduling scheme	Mode2

Overall latency results:

Scenario#	**Mandatory+optional**		**Only mandatory**	
	Mean	Max	Mean	Max
S1: SL	134.6	173.1	52.5	86
S2-1: UL→DL_uc	334.8	534.8	70.8	110.8
S2-2: UL→DL_mbms	141	201	91	151
S2-3: UL→DL_scptm	121.5	162	71.5	112
S3A-1: SL→UL→DL_uc	472.4	710.9	126.3	199.8
S3A-2: SL→UL→DL_mbms	278.6	377.1	146.5	240
S3A-3: SL→UL→DL_scptm	259.1	338.1	127	201
S3B-1: UL→DL_uc→SL	422.4	660.9	126.3	199.8
S3B-2: UL→DL_mbms→SL	278.6	377.1	146.5	240
S3B-3: UL→DL_scptm→SL	259.1	338.1	127	201

For Scenario 2, the control plane latency due to mobility for MBSFN and SC-PTM is analyzed in Table 9.2-1 and Table 9.2-2 respectively.

Table 9.2-1: Average and worst case (in brackets) of MBSFN control plane delay for mobility between MBSFN areas

	Rel-13 values	Possible shorten values in Rel-14	Comments
MIB/SIB1 reading delay	30	30	the acquisition of target cell MIB and SIB1
SIB13 reading delay	40 (80)	40 (80)	Assuming the scheduling periodicity of the SIB13 is 80ms.
Acquisition of MCCH configuration from SIB13	10	10	Processing delay at the UE
Delay due to MCCH scheduling period	160 (320)	10 (20)	For MCCH Repetition period of 320ms (Rel-13 value) and 20ms (possible shorten value).
Acquisition of MCCH and MTCH configuration for TMGI	10	10	Processing delay at the UE
Time required if acquisition of multiple MCCHs is required.	50 (100)	10 (20)	Maximum MCCH offset value is 100ms (Rel-13 value) or 20ms (possible shorten value). It is assumed that multiple MCCH is read in parallel
Total time	**300 (550)**	**110 (170)**	

Table 9.2-2: Average and worst case (in brackets) control plane latency for mobility between SC-PTM cells

Component	Rel-13 values (Note)	Rel-13 values	Comments
MIB/SIB1 reading delay	30	30	the acquisition of target cell MIB and SIB1
SC-PTM SIB20 reading delay	0	40 (80)	SIB20 acquisition
Acquisition of the SC-MCCH configuration for SC-MCCH reception	0	10	Processing delay at the UE
Delay due to SC-MCCH repetition period	10 (20)	10 (20)	For SC-MCCH repetition period of 20ms.
Acquisition of SC-MCCH info, e.g. TMGI to Group-RNTI mapping	10	10	Processing delay at the UE
Total time	**50 (60)**	**100 (150)**	

Note: Considering that SC-RNTI is hard coded in specification, if the UE continuously monitors the SC-RNTI PDCCH after cell change, the UE can acquire the SC-MCCH transmissions before acquiring the SC-PTM SIB20, i.e. the control plane latency due to mobility can be reduced to 50ms on average and 60ms in the worst case.

SIB acquisition delay analyzed in Table 9.2-1 and Table 9.2-2 can be reduced by UE implementation for idle mode UEs.

9.2.2 Observations

The following observations are made based on the results of the latency analysis in section 9.2.1 for the agreed evaluation scenarios:

- The latency requirements can be met for Scenario 1 (mode 1) when SR is set to 1ms or 10ms, the UE is in RR C CONNECTED and assuming mean value.
- The latency requirements can be met for Scenario 2 using Unicast, MBSFN or SC-PTM for connected mode U Es assuming:
  - 20ms backhaul delay and no delays related to mobility
  - Short scheduling period (i.e. SR or SPS period - 1ms and 10ms)
  - For MBSFN the scheduling period set to 40ms
- The latency requirements can be met for Scenario 2 using SC-PTM for idle mode UEs assuming:

  - 20ms backhaul delay and no delays related to mobility
  - SR set to 1ms and 10ms
  - Scheduling period 10ms for mean and 1ms for max (see the definition of mean and max in B.2.1)

- Scenario 3 analysis is down-prioritized.
- For SC-PTM, the control plane latency due to mobility may be a problem for per-location TMGI. Assuming that the UE can continuously monitor PDCCH after cell change, the control plane latency due to mobility can be further reduced when using common G-RNTI.
- For MBSFN, the control plane latency due to mobility may be a problem for both common and per-location TMGI, especially in small size MBSFN areas.

9.3 Power consumption analysis

This section provides the power consumption analysis result for V2P services.

Reception of the paging and (WAN) synchronization only case can be considered as a baseline for power consumption analysis for V2P services [29]. The paging cycle of 1.28 seconds is assumed as shown in [4]. The power consumption occurs from WAN synchronization, paging and sleep power during the paging cycle. The equation and the analysis result for this baseline model is as follows:

Baseline:

(WAN synchronization power + Paging power + Sleep power)/(Paging period)
= (8 subframe*1 unit+1 subframe*1 unit+(1280-(1+8)) subframe*0.01 unit)/1280 subframe
= 0.017 unit/subframe

In PC5-based V2P/P2V, it is observed that the scenario of P-UE TX to V-UE RX is more battery efficient than the scenario of V-UE TX to P-UE RX. It is noted that this observation is made based on evaluations from a limited number of companies.

Figure 9.3-1 shows the result for PC5-based V2P for the two scenarios relative to the baseline power consumption with and without GPS reception power; the first scenario where V-UE is the transmitter (the left case of Figure 4-1(c)) and the second scenario where P-UE is the transmitter (the right case of Figure 4-1(c)).

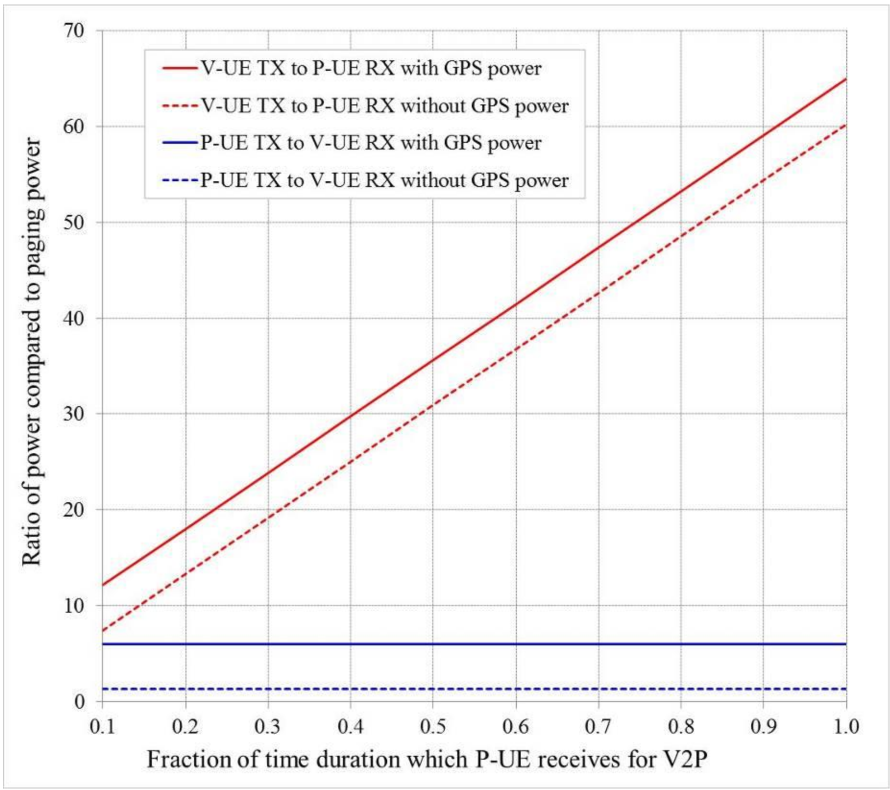


Figure 9.3-1: Power consumption in PC5-based V2P services

In Uu-based V2P/P2V, the multi-cell (7cell clustering) broadcast scheme is assumed as shown in Figure 1 in [30] (i.e., a cell transmits message generated in it in one subframe out of a set of 7 subframes, and it transmits messages generated in neighboring cells in the remaining 6 subframes of the set). In addition, each pedestrian UE knows which subframe is used for transmission of messages generated in which cell. Then, a UE can determine in each subframe whether one of the messages transmitted in the subframe potentially is generated by a vehicle within the target range from it. If so, the UE attempts to receive it, and goes to idle otherwise. As a result, the location of each pedestrian UE determines how many subframes the UE needs to monitor, and this is equal to the number of cells overlaps with the circle having the radius of the target range.

Figure 9.3-2 shows an example of cell deployment and road grid. If the reception coverage of P-UE is the 75m, the ratio of the region which requires reception from 1, 2, 3 and more than 3 cell is about 12, 27, 60, and 0% of total sidewalk, respectively.

For 100% usage of DL subframes, the average power consumption becomes 0.354 units/subframe (i.e. 0.354=(1*0124+2*0.273+3*0.604)/7) where the power consumption becomes 1 units/subframe if the UE monitors all the subframes. It can be generalized as "0.354*X units/subframe" where X is the portion of DL subframes used for V2P transmissions. Table 9.3-1 and Figure 9.3-3 show the ratio of V2P Rx power consumption to baseline power consumption, with consideration for the portion of DL subframes used for V2P transmissions.

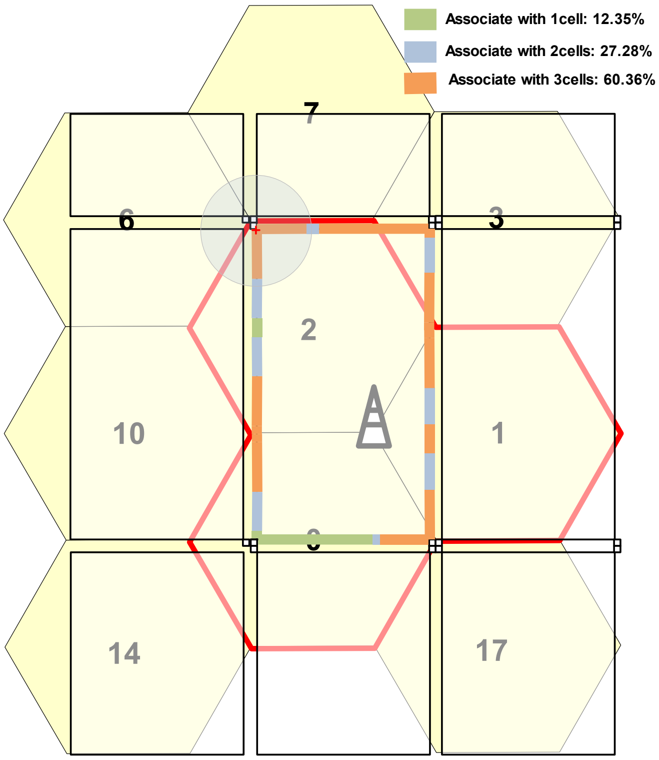


Figure 9.3-2: Uu-based V2P for 7cell clustering

Table 9.3-1: Ratio of V2P Rx power compared to paging power

Portion of DL subframes used for V2P transmissions	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
P-UE Rx for Uu V2P (w/o GPS)	2.08	4.16	6.25	8.33	10.41	12.49	14.58	16.66	18.74	20.82
P-UE Rx for Uu V2P (with GPS)	6.79	8.87	10.95	13.04	15.12	17.20	19.28	21.36	23.45	25.53

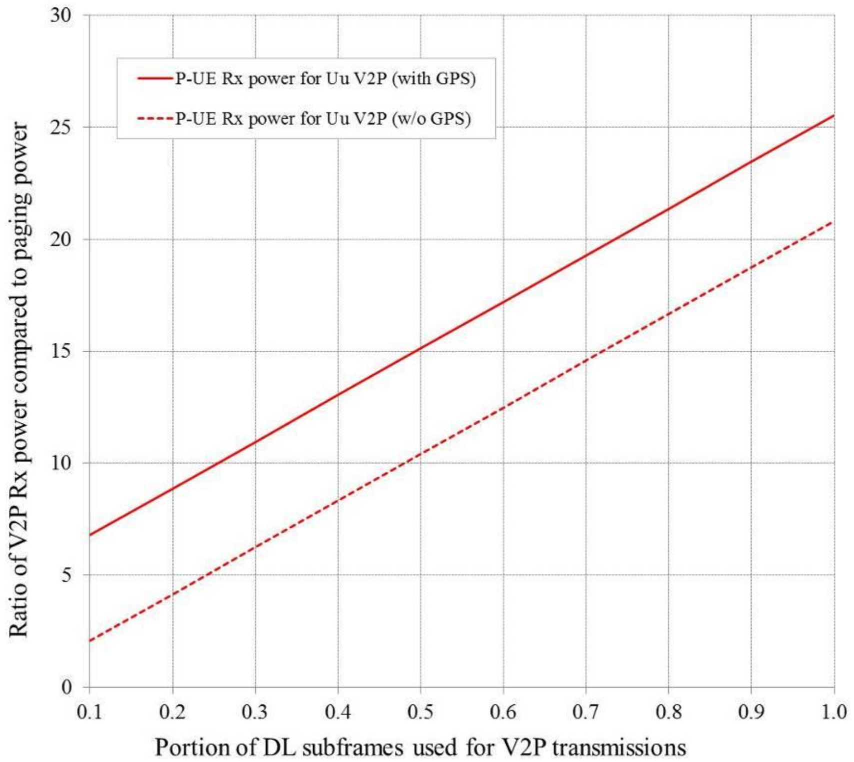


Figure 9.3-3: Ratio of V2P Rx power compared to paging power (considering the portion of DL subframes used for V2P transmissions)

For Uu-based P2V Tx case, the power consumption depends on the scheduling methods. Both dynamic (i.e. SR w/o BSR and SR w/ BSR) and semi-persistent (i.e. SPS) scheduling methods can be considered. The baseline model for P2V power consumption is same as V2P case as described above.

Basically, WAN synchronization is needed once per (P2V) data Tx (e.g. per 1 seconds). For P2V data Tx period of 1 seconds, the P-UE should receive 1/1.28 paging occasion in average. The power consumption occurs from WAN synchronization, paging, SR / BSR Tx (for dynamic scheduling), UL grant reception (for dynamic scheduling), P2V Tx, and sleep power during the P2V data Tx period. The interval between SPS activation / deactivation is different case by case and it can be assumed to be large enough compared to the SPS periodicity. Hence, no DCI reception for SPS activation / deactivation is assumed. Tx power for P-UE is assumed as 23dBm which is interpreted as 4 units in D2D power consumption model. The equations and the analysis results for P2V Tx are as follows:

<u>P2V – SR w/o BSR:</u>

(WAN synchronization power + Paging power + SR Tx power + UL grant Rx power (for data Tx) + Data Tx power + Sleep power)/(Data Tx period) + GPS power

= (8 subframe*1 unit + (1/1.28) subframe*1 unit + 1 subframe*4 unit + 1 subframe*1 unit + 1 subframe*4 unit + (1000-(8+1/1.28+1+1+1)) subframe*0.01 unit)/1000 subframe + 0.08 unit/subframe

= 0.0277+0.08 = 0.108 unit / subframe

<u>P2V – SR w/ BSR:</u>

(WAN synchronization power + Paging power + SR Tx power + UL grant Rx power (for BSR) + BSR Tx power + UL grant Rx power (for data Tx) + Data Tx power + Sleep power)/(Data Tx period) + GPS power

= (8 subframe*1 unit + (1/1.28) subframe*1 unit + 1 subframe*4 unit + 1 subframe*1 unit + 1 subframe*4 unit + 1 subframe*1 unit + 1 subframe*4 unit + (1000-(8+1/1.28+1+1+1+1+1)) subframe*0.01 unit)/1000 subframe + 0.08 unit/subframe

= 0.0326+0.08 = 0.113 unit / subframe

P2V – SPS:

(WAN synchronization power + Paging power + Data Tx power + Sleep power)/(Data Tx period) + GPS power

= (8 subframe*1 unit + (1/1.28) subframe*1 unit + 1 subframe*4 unit + (1000-(8+1/1.28+1)) subframe*0.01 unit)/1000 subframe + 0.08 unit/subframe

= 0.0227+0.08 = 0.103 unit / subframe

For P-UE TX case, it can consider some additional wake-up (or monitoring time) at the UE side around the actual TX subframe, e.g., to monitor whether eNB sends additional UL grant for retransmission. Table 9.3-2 and Figure 9.3-4 show the ratio of P2V Tx power consumption to baseline power consumption, with consideration for the additional monitoring time. It can be shown that the power consumption is increased linearly as the monitoring time increases. However, the message generation rate is rather low (e.g., 1Hz), the power consumption of P2V with some reasonable monitoring time (e.g., up to 100ms) of V2X message may be still lower than V2P with more than 40% of DL resource usage.

Table 9.3-2: Ratio of P2V Tx power compared to paging power

Monitoring time		0	10	20	30	40	50	60	70	80	90	100
SR w/o BSR	w/o GPS	1.63	2.21	2.79	3.37	3.96	4.54	5.12	5.70	6.29	6.87	7.45
	w/ GPS	6.33	6.92	7.50	8.08	8.66	9.24	9.83	10.41	10.99	11.57	12.16
SR w/ BSR	w/o GPS	1.92	2.50	3.08	3.67	4.25	4.83	5.41	6.00	6.58	7.16	7.74
	w/ GPS	6.63	7.21	7.79	8.37	8.96	9.54	10.12	10.70	11.28	11.87	12.45
SPS	w/o GPS	1.33	1.92	2.50	3.08	3.66	4.25	4.83	5.41	5.99	6.58	7.16
	w/ GPS	6.04	6.62	7.20	7.79	8.37	8.95	9.53	10.12	10.70	11.28	11.86

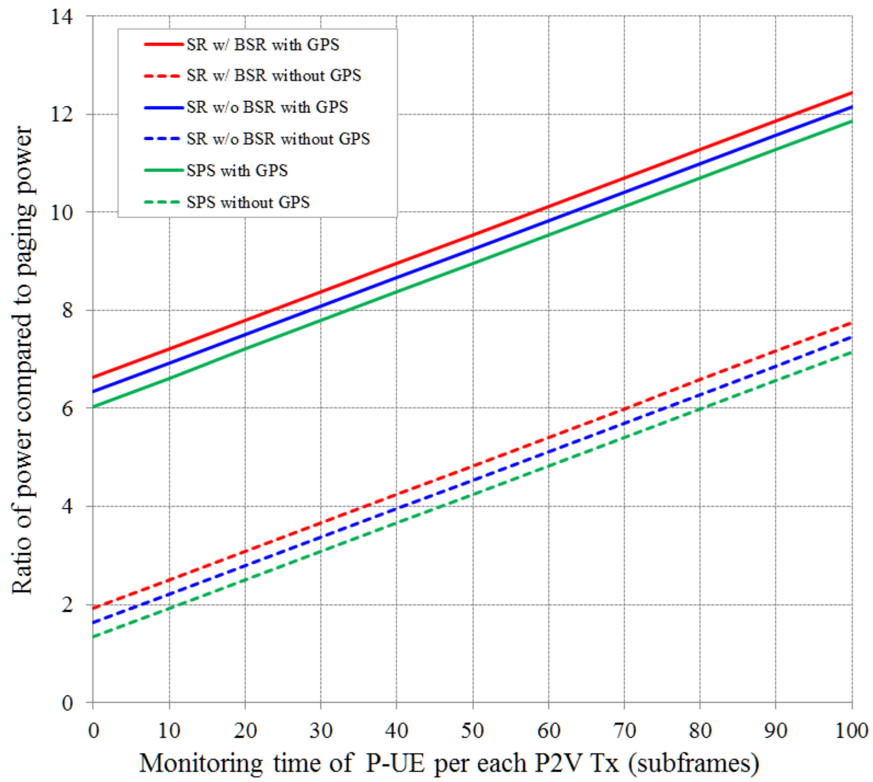


Figure 9.3-4: Ratio of P2V Tx power compared to paging power (considering the monitoring time)

10 Coexistence with DSRC/IEEE 802.11p in the same channel

- RAN1 has discussed co-existence between DSRC and LTE-based ITS (sidelink) for safety ITS. RAN1 believe s that ITS systems are important and should protect each other and in particular safety ITS.
- Technology neutrality is essential in order to enable choice of most suitable radio technology for each ITS serv ice as well as to enable a technology phasing in the future (e.g., towards 5G)
- RAN1 believes that technology neutrality is enabled by describing common coexistence rules that are followed by all potential ITS technologies. Such rules may be specific for a certain region. RAN1 believes that the detai ls of the common coexistence rules are out of RAN1 scope and should be discussed in relevant SDOs in each r egion.
- For deployment of PC5-based LTE-V2V and 802.11p in the same geographical area, the ideal option is when t hey use different frequency channels. Note that co-deployment of both technologies is not likely to happen in a ll regions.
- RAN1 believes that other radio access technologies and LTE-based ITS transmissions on sidelink can co-exist; some standardization and/or regulatory actions need to be taken in other bodies in order to enable this.
- The possible solutions identified by RAN1 for high level coexistence approaches (long-term basis) between PC 5 transport for V2V services and DSRC/IEEE 802.11p services in the same channel are as follows:
  - Geo-location and database.
  - Time sharing between systems based on GNSS timing; this would require some modifications to DSR C.
  - Sensing-based vacate/switching approaches with or without transmission of a predetermined signal(s)

(e.g. LTE-ITS preamble, SLSS)

    - Sensing with a predetermined signal(s) would require some modifications to DSRC.
    - RAN1 has not conducted any system-level evaluations for these solutions, although some link-level re sults have been provided for some solutions.

11 Conclusions

It is feasible to support V2V services based on LTE PC5 interface with necessary enhancements. As identified, it is recommended to enhance at least LTE sidelink resource allocation, physical layer structure, and synchronization.

The RAN WGs concluded that it is feasible to support transport for V2V, V2I/N and V2P services over Uu. The RAN WGs identified solutions to improve the latency, capacity, and reliability performance of LTE Uu interface and observed that UL enhancements to the SPS protocol and DL enhancement to multicast/broadcast are beneficial from performance perspective. It is recommended to support the following solutions identified in this TR for Uu-based V2X:

- Transmission using a single CP shorter than extended CP, with normal CP as the baseline, with necessary addit ional study
- HARQ feedback and retransmissions for SC-PTM and MBSFN, with necessary additional study
- Geo-information report from RRC_Connected UEs
    - No additional specification work is needed.

The RAN WGs concluded that it is feasible to support V2I and V2P services over PC5. It is concluded that V2P services where P-UE sends V2X messages but not receives V2X messages is substantially more power efficient than V2P services where P-UE receives V2X messages from V-UEs. The RAN WGs identified that some changes to the PC5 interface would be beneficial in terms of power consumption and UE complexity in case of P2V transmissions. It is recommended to support following solutions identified in this TR for PC5-based V2X:

- Random resource selection for P-UEs potentially on the resource pool shared with V-UE transmissions, with a dditional study on sensing operation during a limited time for P-UEs

Annex A: Evaluation methodology

For PC5-based V2V, tradeoff between system and link level performance can be studied. Assumption on the target link budget in link level is as follows:

- 150 m in NLOS Urban case
- 320 m in Freeway case

A.1 System level simulation assumptions

For PC5-based V2V, the following general assumptions apply:

- Each vehicle UE's reception is subject to the half duplex constraint.

For evaluation of DL broadcast/multicast for V2V, companies should clarify the following in submitting results:

- MCS setting with the reasoning why such a setting is used
- Allowed buffering delay in eNB
- Average number of vehicles in a cell
- Amount of used resources and scheduling policy

A.1.1 Evaluation scenarios

Two vehicle UE dropping cases are defined: Urban case and Freeway case. See Section A.1.2 for the UE drop and mobility model in each case. Section A.1.2 also contains dropping model for pedestrian UEs. See Section A.1.4 for the channel model in each case.

Macro eNB may or may not be deployed in the evaluations. If deployed, the assumptions in Section A.1.3 should be used. If not, simple wrap around can be used as long as it is aligned with the evaluation assumptions in this TR. Section A.1.3 also contains RSU deployment model.

Details of evaluation scenarios are in Table A.1.1.-1.

Table A.1.1-1: Details of evaluation scenarios

Parameter	Assumption
Carrier frequency	- PC5 based V2V: 6 GHz[1], 2 GHz - V2I: 6GHz (Baseline) for UE type RSU, 2GHz for eNB type RSU
Bandwidth	- PC5 based V2V: 10 MHz - V2I: 10MHz for UE type RSU, 10MHz for each of DL and UL in FDD;

[1] Note that the system should work for all the bands up to 6 GHz, including 5.9 GHz. This study is not intended to make any implication for the study on channel above 6 GHz.

		20MHz in TDD for eNB type RSU - V2P: 10 MHz is baseline.
Number of carriers		One carrier is baseline. Other numbers can be evaluated based on inter-carrier interference model from the existing UE-UE link ACIR [28] dB according to [5] for the adjacent channel case.
Synchronization		Time and frequency error should be considered in system and link level simulations. Companies should explain the assumed error model and the method to achieve the error range. Until RAN4 provides an answer, RAN1 will assume at least the case where frequency error (i.e., error in the oscillator) is in the range of +- 0.1 PPM.
Vehicle UE , UE type RSU, Pedestrian UE parameters	In-band emission	In-band emission model in Section A.2.1.5 in [4] is reused with {W, X, Y, Z} = {3, 6, 3, 3} for single cluster SC-FDMA.
	Antenna height	1.5 m for vehicle UE and pedestrian UE, 5 m for UE type RSU
	Antenna pattern	Omni 2D
	Antenna gain	3 dBi for vehicle UE and UE type RSU, 0 dBi for pedestrian UE
	Maximum transmit power	23 dBm
	Number of antennas	1 TX and 2 RX antennas. Baseline is that 2 RX antennas are separated by wavelength/2.
	Noise figure	9 dB

For the evaluation of V2I, the following assumptions are used. The evaluation statistics according to performance metric are provided for V2I and I2V respectively.

- UE type RSU
  - Evaluation scenario with following bullets
    - Baseline: Urban only
    - Optional: Freeway
  - Baseline: V2I and I2V transmission shares the same carrier
    - Not preclude they are using separate/multiple carriers
  - PC5 based V2V is included in V2I (UE type) simulation to reflect realistic UE density
    - i.e. The difference from PC5 V2V evaluation will be additional receivers (″I″) receiving the same traffic as PC5 V2V evaluation from vehicle; and additional transmitters (″I″)
  - When PC5 is considered co-channel with uplink
    - Half duplex constraint is respected
  - When considering separate carrier for PC5 from uplink
    - Companies to indicate whether half duplex constraint is respected between PC5 and uplink
  - When PC5 V2V is considered at separate carrier from V2I
    - Companies to indicate whether half duplex constraint is respected between PC5 V2V and V2I

  - Evaluation results are provided for both I2V and V2I

- eNB type RSU
  - Evaluation scenario with following bullets
    - Baseline: Urban only
    - Optional: Freeway
  - Uu interface
  - Baseline: Macro eNB in urban case
  - Baseline: Simulation of V2I (eNB type) simulation is separated from PC5 based V2V (main scenario to evaluate: Uu and PC5 co-channel)
    - When PC5 is considered co-channel with uplink
      - Half duplex constraint is respected
      - Companies provide details about scheme for half duplex constraint, e.g. the subset of subframes used for Uu
    - When considering separate carrier for PC5 from uplink
      - Companies to indicate whether half duplex constraint is respected between PC5 and uplink
  - Considering WAN traffic on the same carrier of V2I
  - UL and DL simulations can be separated
  - Evaluation results are provided at least for both V2I and I2V

For the evaluation of V2P, the following assumptions are used.

- Companies should explain how to combine V2P (i.e., vehicle UE transmission and pedestrian UE reception), P2V (i.e., pedestrian UE transmission and vehicle UE reception), V2V and assume half duplex constrain in the evaluation
  - Separate statistics for P2V, V2P, V2V

A.1.2 UE drop and mobility model

Vehicle UEs are dropped on the roads according to spatial Poisson process. The vehicle density is determined by the assumption on the vehicle speed, and the vehicle location should be updated every 100 ms in the simulation.

In Urban case, a vehicle changes its direction at the intersection as follows:

- Go straight with probability 0.5
- Turn left with probability 0.25
- Turn right with probability 0.25

Details of vehicle UE drop and mobility model for each of Urban and Freeway cases are in Table A.1.2-1. Figures A.1.2-1 and A.1.2-2 illustrate the road configuration of the two cases.

Table A.1.2-1: Details of vehicle UE drop and mobility model

Parameter	Urban case	Freeway case
Number of lanes	2 in each direction (4 lanes in total in each street)	3 in each direction (6 lanes in total in the freeway)
Lane width	3.5 m	4 m
Road grid size by the distance between intersections	433 m * 250 m. Note that 3 m is reserved for sidewalk per direction (i.e., no vehicle or building in this reserved space)	N/A
Simulation area size	Minimum [1299 m * 750 m]	Freeway length >= 2000 m. Wrap around should be applied to the simulation area.
Vehicle density	Average inter-vehicle distance in the same lane is 2.5 sec * absolute vehicle speed. Baseline: The same density/speed in all the lanes in one simulation.	
Absolute vehicle speed	15 km/h, 60 km/h	140 km/h, 70 km/h[2]

2 The intention is to capture the sparse and medium cases in [6].

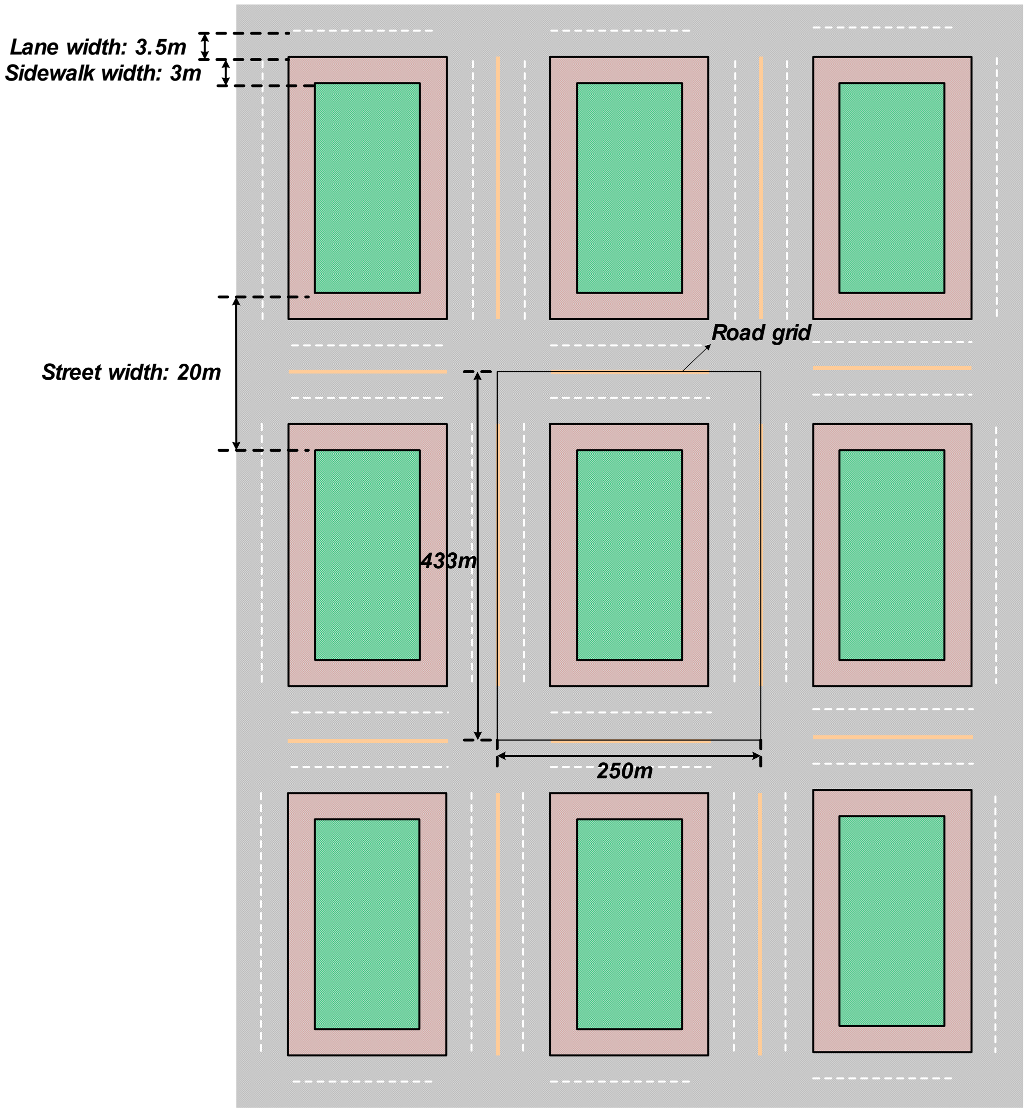


Figure A.1.2-1: Road configuration for Urban case

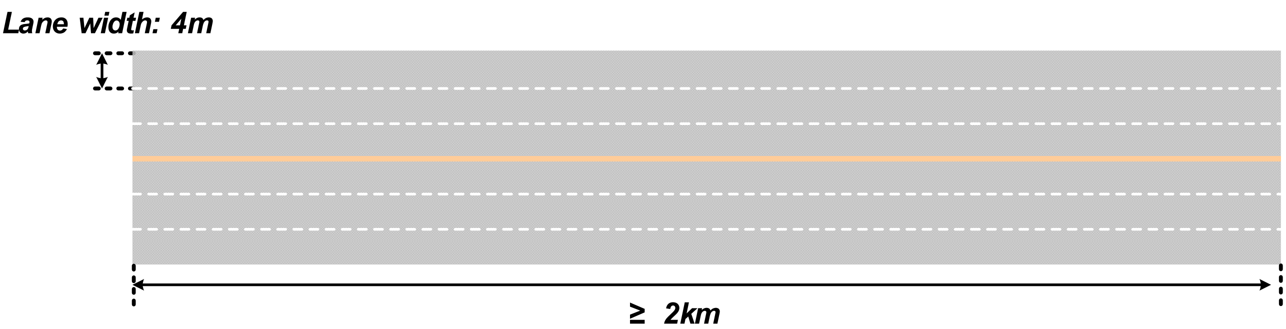


Figure A.1.2-2: Road configuration for Freeway case

Details of pedestrian UE drop and mobility model are as follows:

- Urban case only

- Pedestrian UE dropping using equally spaced along the sidewalk with a fixed inter-pedestrian X m dropped
  - Total number of pedestrian UEs is 500
  - Pedestrian UE is in the middle of the sidewalk
  - The inter-pedestrian UE distance (m) (i.e., X) is calculated by 'A/500', where 'A' is the total length of sidewalk where the pedestrian UEs are dropped under the assumption of 'N' road grids (i.e., '{(250m – 17m) + (433m – 17m)} * 2 * N'). For example, if the pedestrian UEs are dropped in '14' road grids, the inter-pedestrian UE distance (m) is '36.344'.
    - Companies should explain how many road grids (i.e., 'N") are assumed in the evaluation.
- Pedestrian UE speed is 3 km/h

A.1.3 eNB and RSU deployment

If macro eNBs are deployed for Urban case, ISD of macro eNB is 500 m and the wrap around model in Figure A.1.3-1 is used.

If macro eNBs are deployed for Freeway case,

- Option 1 (baseline): eNBs are located along the freeway 35m away with 1732m ISD in Figure A.1.3-2.
- Option 2 (optional): Wrap around method of 19*3 hexagonal cells with 500m ISD in Figure A.1.3-3.

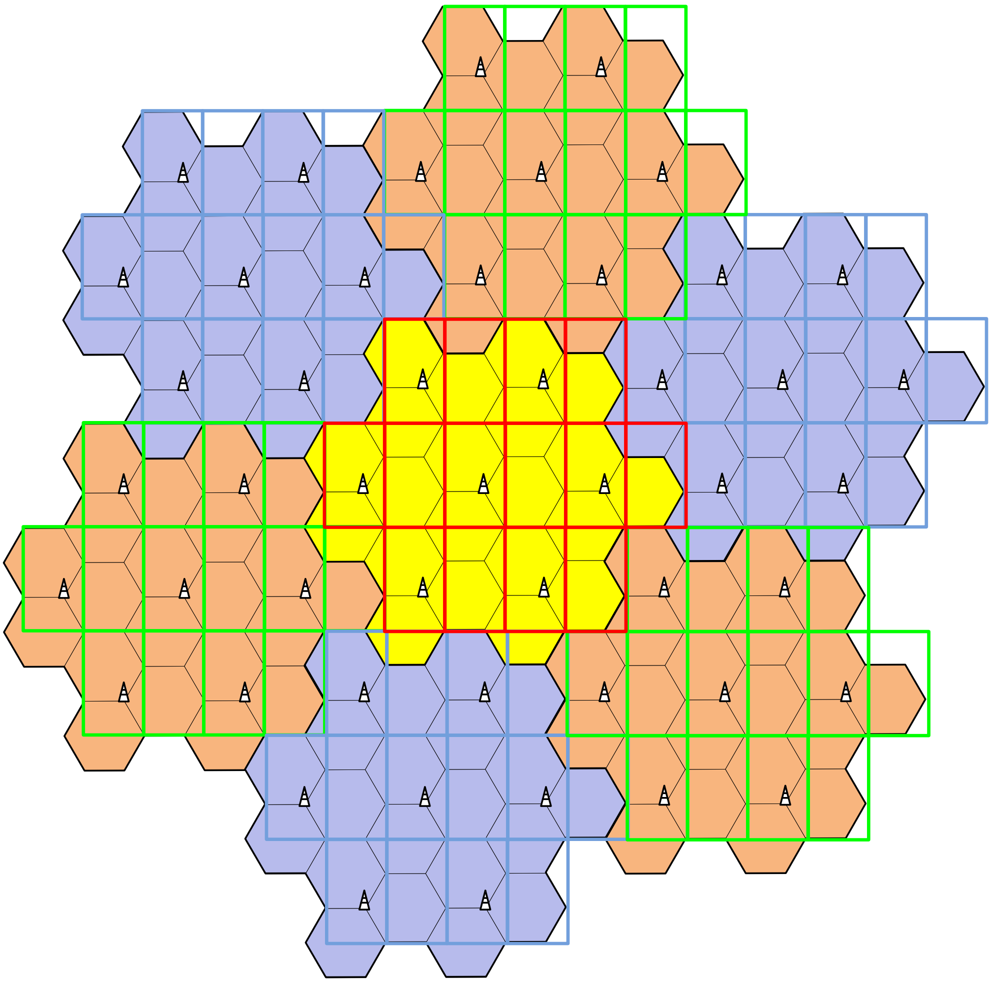


Figure A.1.3-1: Wrap around model for Urban case

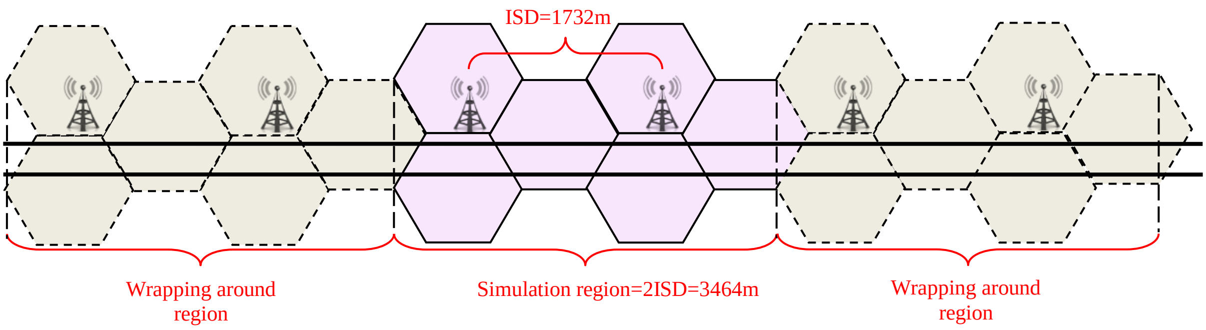


Figure A.1.3-2: Wrap around model option 1 (baseline) for Freeway case

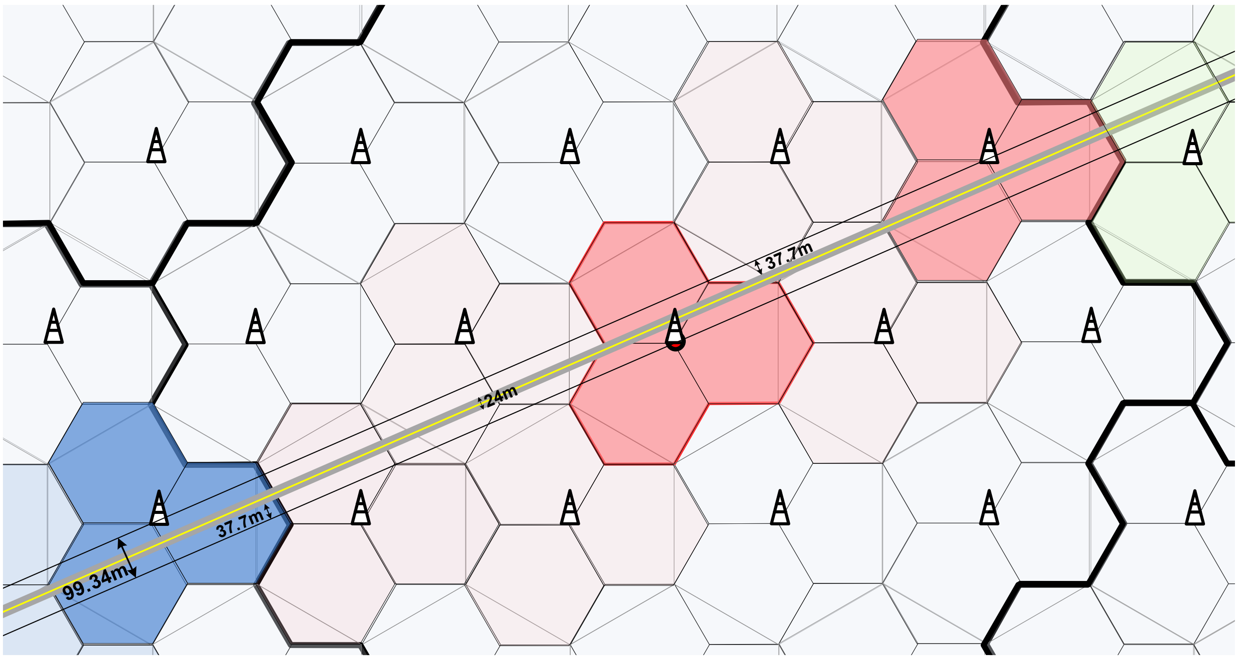


Figure A.1.3-3: Wrap around model option 2 (optional) for Freeway case

FFS on how to handle mobility and handover related issue

Details of RSU drop model for each of Urban and Freeway cases are as follows:

- UE type RSU
  - Urban: at the center of intersection
  - Freeway: uniform allocation with 100m spacing in the middle of the freeway
- eNB type RSU
  - Dropping: the same as eNB dropping in PC5 V2V evaluation

A.1.4 Channel model

Assumptions for channel between two vehicle UEs are in Table A.1.4-1.

Table A.1.4-1: Assumptions for vehicle-to-vehicle channel

Parameter	Urban case	Freeway case
Pathloss model	WINNER+ B1 Manhattan grid layout (note that the antenna height should be set to 1.5 m.). Pathloss at 3 m is used if the distance is less than 3 m.	LOS in WINNER+ B1 (note that the antenna height should be set to 1.5 m.). Pathloss at 3 m is used if the distance is less than 3 m.

Shadowing distribution	Log-normal	Log-normal
Shadowing standard deviation	3 dB for LOS and 4 dB for NLOS	3 dB
Decorrelation distance	10 m	25 m
Fast fading	NLOS in Section A.2.1.2.1.1 or A.2.1.2.1.2 in [4] with fixed large scale parameters during the simulation.	

Vehicle-to-vehicle channels are updated during the simulation as follows:

- Let N be the number of vehicle UE in system simulation
- Initialization (at time 0)
  - N vehicle locations are generated per agreed drop model
  - PL (0) – NxN matrix generated as per vehicle locations and agreed channel models
  - Shadowing (in log domain): S(0) – NxN i.i.d. (with the exception that shadowing between two vehicles should be the same in the two directions) normal matrix generated as per agreed shadowing model
  - Fading (0) – NxN i.i.d. processes with a common distribution
- Update (at time 100*n ms)
  - Vehicle locations are updated as per agreed update rules
  - PL(n) – N x N matrix generated as per updated vehicle locations
  - S(n) = exp(-D/D_corr) .* S(n-1) +sqrt{ (1-exp(-2*D/D_corr))}.*N_S(n)
    - where N_S(n) is an NxN i.i.d. (with the exception that shadowing between two vehicles sho uld be the same in the two directions) normal matrix generated as per the agreed shadowing model
    - D is the update distance matrix where D(i,j) is change in distance of link i to j from time n-1 to time n
  - Fading process is not impacted due to vehicle location updates – fading is only updated due to time
  - UE performance should reflect fast fading variation within the subframe

Assumptions for channel between a UE and a macro eNB in the cell layout in Figures A.1.3-1, A.1.3-2, and A.1.3-3 are in Table A.1.4-2. For Urban case and option 2 of Freeway case, assumptions not in Table A.1.4-2 are the same as the assumptions of 3GPP case 1 in A.2.1.1.1 in [7]. For option 1 of Freeway case, assumptions not in Table A.1.4-2 are the same as the assumptions of 3GPP case 3 in A.2.1.1.1 in [7].

Table A.1.4-2: Assumptions for channel between UE and macro eNB

Parameter	Assumption
Pathloss model	128.1 + 37.6log10(R), R in kilometers
Penetration loss	0 dB
Shadowing distribution	Log-normal
Shadowing standard deviation	8 dB
Decorrelation distance	50 m
Fast fading	3GPP Spatial Channel Model (SCM) NLOS in [7] with fixed large scale parameters during the simulation.

Shadowing is updated as follows:

- Let M be the number of eNB sites
- Initialization (at time 0)
    - Shadowing: $S_{eNB2UE,i}(0) = R*N_i(0)$

$$R = \begin{bmatrix} 1 & 0.5 & \cdots & 0.5 \\ 0.5 & 1 & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0.5 \\ 0.5 & \cdots & 0.5 & 1 \end{bmatrix}^{1/2}$$

        - R is a MxM matrix to generate shadowing correlation between eNB sites.
            - A Shadowing correlation factor of 0.5 for the shadowing between eNB sites and of 1.0 between sectors of the same eNB site are used
        - $S_{eNB2UE,i}(0)$: Mx1 shadowing values between the ith UE and eNB sites
        - $N_i(0)$: Mx1 i.i.d. normal vector generated for the ith UE.
- Update (at time 100*n ms)
    - UE locations are updated as per A.1.2.
    - $S_{eNB2UE,i}(n) = \exp(-D_i/D\_corr) .* S_{eNB2UE,i}(n-1) + \text{sqrt}\{(1-\exp(-2*D_i/D\_corr))\}.*(R*N_i(n))$
        - where $N_i(n)$ is an Mx1 i.i.d. normal vector for the ith UE.
        - D_i denotes the update distance matrix for the ith UE where $D_i(k,k)$ is change in distance of the ith UE to the kth eNB site from time n-1 to time n. Note that D_i is a diagonal matrix.
        - D_corr = 50m

Assumptions for channel model between a UE and a RSU are as follows:

- UE type RSU
    - Reuse that for UE-UE in PC5 based V2V evaluation with antenna height at RSU changed to 5m
- eNB type RSU
    - Reuse that for eNB-UE in PC5 V2V evaluation

For I2I channel model between two UE type RSUs, the V2V channel model with antenna heights equal to 5 m is used.

Assumptions for channel model between a pedestrian UE and a vehicle UE are as follows:

- Reuse the vehicle-to-vehicle pathloss, fading, and shadowing models with the following modifications:
    - Pedestrian UE speed is 3 km/h
    - Location update is not modelled for pedestrian UE
    - Antenna height and gain of pedestrian UE are 1.5m, 0 dBi respectively

Assumptions for channel model between a pedestrian UE and eNode B are the same as agreed V2N channel model.

A.1.5 Traffic model

- Traffic model for V2V

There are two traffic models used in evaluation: Periodic traffic case and Event-triggered traffic case. Periodic traffic case is mandatory. Event-triggered traffic case can be evaluated optionally with or without Periodic traffic.

Every vehicle in the simulation generates messages according to the traffic model.

For Periodic traffic, message generation periods are defined in the following 5 distinctive scenarios in Table A.1.5-1.

Table A. 1.5-1: Message generation period for Periodic traffic

Index	Vehicle dropping scenarios	Absolute vehicle speed (km/h)	Message generation period (ms)
1	Freeway	140	100
2	Freeway	70	100
3	Urban	60	100
4	Urban	15	100
5	Urban	15	500

For Periodic traffic, working assumption of message size is that one 300-byte message followed by four 190-byte messages, and the time instance of 300-byte size message generation is randomized among vehicles. Note that it is allowed not to consider message size in calculating the performance metric.

For Event-triggered traffic, event arrival follows Poisson process with the arrival rate X (up to company choice) per second for each vehicle. Once event triggered, 6 messages are generated with space of 100ms. Working assumption of message size for Event-trigger traffic at L1 is 800bytes.

- Traffic model for V2I

Details of traffic model for V2I are as follows:

- V2I/I2V traffic model 1: Message generation frequency is the same as that of V2V. Latency requirement is 100 ms.
- V2I/I2V traffic mode 2: Message generation frequency is 1 or 0.1 Hz. Latency requirement is > 100 ms (e.g., 1000 ms).
- I2V traffic is generated per intersection for urban case
- For the freeway case, I2V message generation points are "uniformly located with 100m spacing in the middle of the freeway ."
  - The location of I2V message generation point is the same as that of UE type RSU.
- The message size is the same as that of V2V traffic model for V2I/I2V traffic model 1, and is fixed to 300 Bytes for V2I/I2V traffic model 2.
- V2V message generation does not change from the existing model.
- For model 1, a single message is generated at a vehicle both for V2V and V2I (i.e, no change in the traffic load).
- For model 2, V2I message is additionally generated on top of the V2V message.
- For communication range,
  - Half of that of V2V for I2V traffic model 1.
  - For I2V traffic model 2, company should provide the value of communication range assumed in the evaluation.
    - The communication range of I2V traffic model 2 should be larger than that of I2V traffic model 1.

- Traffic model for V2P

Details of traffic model for V2P are as follows:

- Traffic model for vehicle UE's transmission in case of V2P
  - The existing traffic model of V2V is reused.
- Traffic model for pedestrian UE's transmission in case of P2V
  - The message size is fixed at 300 Bytes and transmission frequency is 1 Hz.
- For V2P,
  - '100ms' latency requirement (i.e., Same as that defined in V2V)
- For P2V,
  - Baseline: '100ms' latency requirement

When another value of latency requirement larger than 100ms (e.g., 1000ms) is assumed in the evaluation, companies should explain it.

A.1.6 Performance metric

For evaluation of proposed schemes for V2V, the following metric(s) shall be considered.

- Packet Reception Ratio (PRR) :
  - For one Tx packet, the PRR is calculated by X/Y, where Y is the number of UE/vehicles that located in the range (a, b) from the TX, and X is the number of UE/vehicles with successful reception among Y. CDF of PRR and the following average PRR are used in evaluation
    - CDF of PRR with a = 0, b = baseline of 320 meters for freeway and 150 meters for urban. Optionally, b = 50 meters for urban with 15 km/h vehicle speed[3].
    - Average PRR, calculated as (X1+X2+X3….+Xn)/(Y1+Y2+Y3…+Yn) where n denotes the number of generated messages in simulation. with a = i*20 meters, b = (i+1)*20 meters for i=0, 1, …, 25

- FFS Packet Inter-Reception (PIR): time elapsed between two successive successful receptions of two different packets transmitted from node A to node B

Companies should explain the amount of time and frequency resources used for simulation.

For evaluation of proposed schemes for V2I, the performance metric is the same as that for V2V except for target communication range.

For evaluation of proposed schemes for V2P, the following metric(s) shall be considered.

- For pedestrian UE in case of V2P,
  - The power consumption model defined in [4] is used as an additional performance metric to evaluate the power consumption caused by the reception of pedestrian UE.

3 This optional value shall not be used to justify the fulfilment of SA1 requirements. It shall only apply to system-level evaluations.

- To evaluate the reception ratio of Vehicle UE's transmission packet, the existing performance metric of V2V (i.e., PRR) is reused with the following modifications.
  - PRR is calculated under the assumption that Vehicle UE's packet transmitted during the time when pedestrian UE sleeps is regarded as the failure of reception.
  - Target range for CDF of PRR and average PRR is the half of that defined in V2V.
- FFS on whether/how to investigate the impact of bursty reception failure caused by sleep of pedestrian UE over consecutive subframes.

- For vehicle UE and pedestrian UE in case of P2V
  - To evaluate the reception ratio of pedestrian UE's transmission packet, the existing performance metric of V2V (i.e., PRR) is reused with the following modifications.
    - Target range for CDF of PRR and average PRR is the half of that defined in V2V.
  - The power consumption model defined in [4] is used as an additional performance metric to evaluate the power consumption caused by the transmission of pedestrian UE.

A.2 Link level simulation assumptions

For fast fading model in PC5-based V2V, channel model in Section A.2.1.2.1.2 in [4] is used.

Message sizes used in link level simulation for V2V are:

- Baseline: 190, 300, 800 bytes
- Other numbers are not precluded

Assumptions for evaluation of DM RS location is as follows:

- Transmissions in a single TTI (i.e., no HARQ retransmission). It is encouraged to evaluate both SA and data.
  - Baseline: QPSK with coding rate of 0.5
  - Optional: QPSK with coding rate of 0.7, 16QAM with coding rate 0.5 (only for data)
  - Frequency error: Baseline is to evaluate both {Case 1+Case B} and {Case 2+Case A}. Other cases can be considered, e.g., based on RAN4 feedback.
    - Case 1: The extreme case should be assumed, i.e., +0.1 PPM for TX and -0.1 PPM for RX w.r.t. UE's sync reference.
      - Performance in Case 1 is to check whether the system can work in the extreme case.
    - Case 2: Frequency error in each UE is uniformly distributed [-0.1, 0.1] PPM w.r.t. UE's sync reference.
  - Frequency error between sync references of TX and RX:
    - Case A: 0 error (i.e., the same reference)
    - Case B: The extreme case should be assumed, i.e., +0.05 PPM for TX's reference and -0.05 PPM for RX's reference w.r.t. the absolute frequency.
- Companies should describe the receiver algorithm of the evaluated options.

Annex B: Detailed evaluation results for PC5-based V2V

B.1 Simulation assumptions

– Periodic traffic scenario

Description		Source 1	Source 2	Source 3	Source 4	Source 5	Source 6	Source 7
		Sceanrio#1, #2, #3, #4, #5	**Sceanrio#1, #2, #3, #4**	**Sceanrio#1, #2, #3**	**Sceanrio#1, #2, #3, #4**	**Sceanrio#1, #2, #3, #4**	**Sceanrio#1, #2, #3, #4, #5**	**Sceanrio#1, #2, #3, #4, #5**
Carrier frequency (GHz)		6	6	6	6	6	6	6
Number of carriers (1 carrier is baseline)		1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1(10MHz)	1(10MHz)	1 (10 MHz)	1 (10 MHz)
Number of subframes used to transmit each message	**190 bytes**	3 (1 control + 2 data)	4 (2 control + 2 data)	1 (control + data)	1	1	4 (4 control + data)	4 (4 control + data)
	300 bytes	4 (1 control + 3 data)	5 (2 control + 3 data)	1 (control + data)	1	1	4 (4 control + data)	4 (4 control + data)
Number of RBs used to transmit each message in each subframe	**190 bytes**	10 RBs	10 RBs	16 RBs	16RBs	16RBs	12 RBs	12 RBs
	300 bytes	10 RBs	10 RBs	32 RBs	16RBs	16RBs	16 RBs	16 RBs
Modulation	**190 bytes**	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK
	300 bytes	QPSK	QPSK	QPSK	16QAM	16QAM	QPSK	QPSK

Transmission power (in case of non-zero MPR, actual power after applying MPR)	23 dBm	23 dBm	23dBm	23dBm	23dBm	23 dBm	23 dBm
Physical channel format (e.g., number of RS symbols)	4 symbol comb-type DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol comb-type DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol comb-type DMRS positioned at #3, #6, #9, #12 for both of control and data	4 symbol comb-type DMRS positioned at #2, #5, #8, #11	4 symbol comb-type DMRS positioned at #2, #5, #8, #11	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data
MPR and inband emission model	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843
Synchronization assumptions	Ideal time synchronization. "1.2KHz' residual frequency offset in every UE-UE link [8]	Ideal time synchronization. "1.2KHz' residual frequency offset in every UE-UE link [8]	Ideal time synchronization	Ideal time synchronization. "1.2KHz' residual frequency offset in every UE-UE link	Ideal time synchronization. "1.2KHz' residual frequency offset in every UE-UE link	Ideal time and frequency synchronization.	Ideal time and frequency synchronization.
SA assumption (e.g., SA overhead)	Control channel containing 30-bit SA is transmitted in a PRB pair in a subframe before the corresponding data transmissions [9]	Control channel containing 30-bit SA (1 PRB pair) is transmitted twice in the control pool before the corresponding data transmissions in the data pool [9]	Control channel containing 60-bit SA is transmitted inband with the corresponding data within the same sub-channel(s)	SA overhead is not assumed	SA overhead is not assumed	The SA and the associated data are transmitted in the same subframe and one SA occupies one PRB.	The SA and the associated data are transmitted in the same subframe and one SA occupies one PRB.
Remark	–	–	–	–	–	–	–

Description	**Source 8**	**Source 9**		**Source 10**		**Source 11**	**Source 12**
	Sceanrio#1, #2, #3, #4	**Sceanrio#1, #2**	**Sceanrio#3, #4**	**Sceanrio#1, #2**	**Sceanrio#3, #4**	**Sceanrio#1, #2, #3, #4**	**Sceanrio#1, #2, #3, #4, #5**
Carrier frequency (GHz)	6	6	6	6	6	6	6

Number of carriers (1 carrier is baseline)		1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)
Number of subframes used to transmit each message	**190 bytes**	4 (control and data in each subframe)	4	4	4	4	2 data	4 (2 control + 2 data)
	300 bytes	4 (control and data in each subframe)	4	4	4	4	2 data	4 (2 control + 2 data)
Number of RBs used to transmit each message in each subframe	**190 bytes**	6 RBs	12 RBs	12 RBs	12 RBs	12 RBs	12 RBs	50RBs
	300 bytes	8 RBs	24 RBs	24 RBs	24 RBs	24 RBs	12 RBs	50RBs
Modulation	**190 bytes**	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK
	300 bytes	QPSK	QPSK	QPSK	QPSK	QPSK	16QAM	QPSK
Transmission power (in case of non-zero MPR, actual power after applying MPR)		21 dBm	23 dBm	23 dBm	23 dBm	23 dBm	23 dBm	23dBm
Physical channel format (e.g., number of RS symbols)		4 DMRS symbols at #2, #5, #9, #12 positions for control and data	15KHz subcarrier spacing, 4 DMRS Symbols at #3, #6, #9, #12	15KHz subcarrier spacing, 4 DMRS Symbols at #3, #6, #9, #12	30KHz subcarrier spacing, 2 DMRS Symbols at #4, #11	30KHz subcarrier spacing, 2 DMRS Symbols at #4, #11	4 symbol comb-type DMRS positioned at #2, #5, #8, #11	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data
MPR and inband emission model		'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	According to SI evaluation assumptions, with {W, X, Y, Z} = {3, 6, 3, 3}	According to SI evaluation assumptions, with {W, X, Y, Z} = {3, 6, 3, 3}	According to SI evaluation assumptions, with {W, X, Y, Z} = {3, 6, 3, 3}	According to SI evaluation assumptions, with {W, X, Y, Z} = {3, 6, 3, 3}	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843
Synchronization assumptions		Ideal time synchronization. For frequency synchronization we	Ideal time frequency synchronization (GNSS/GNSS-	Ideal time frequency synchronization (GNSS/GNSS-	Ideal time frequency synchronization (GNSS/GNSS-	Ideal time frequency synchronization (GNSS/GNSS-	Ideal time synchronization. "1.2KHz" residual frequency offset in every	Ideal time synchronization and frequency offset

	randomly chose frequency offset and apply a corresponding loss.	equivalent)	equivalent)	equivalent)	equivalent)	UE-UE link	
SA assumption (e.g., SA overhead)	48-bit SA is transmitted in the same subframes as DATA and adjacent in frequency with DATA	D2D Rel-12 SA Format	D2D Rel-12 SA Format	D2D Rel-12 SA Format	D2D Rel-12 SA Format	Ideal SA decoding	Control channel occupy 20% of the SA Period,SA and Data is TDM(e.g., Control channel occupy 8 ms when SA Period is 40ms)
Remark	–	15KHz, QPSK, TDM/UE-Cycling, 4 TTIs, T-RPT R-Start Time	15KHz, QPSK, TDM/Geo, 4 TTIs, T-RPT R-Start Time	30KHz, QPSK, TDM/UE-Cycling, 4 TTIs, T-RPT Fully Random	30KHz, QPSK, TDM/Geo, 4 TTIs, T-RPT R-Start Time	–	–

It is further noted that resource allocation principles used by sources are different and are summarized below:

1) Source 1: Collision avoidance based on sensing and location-based resource selection [9]

2) Source 2: Control pool FDMed with data pool, random resource selection and location-based resource selection [9]

3) Source 3:

A. "Sensing based semi-persistent resource occupy":

i. UE sensing available resource via energy measurement and SA decoding.

ii. UE detect resource collision via energy measurement and broadcast it in SA.

iii. Once selected from available resources, the resource is persistently occupied by UE, until been notified as collision by other UE(s).

iv. See more detail in [10]

4) Source 4:

A. Collision avoidance:

i. Assuming UE enters NW one by one, and randomly selects a subframe within a set of least interfered subframes, and then selects the least interfered Freq. resource in the subframe [11]

5) Source 5:

A. eNB scheduling with UE location information:

i. eNB schedules UE to a subframe such that the minimum distance to other UEs assigned the same SF is largest, and then selects Freq. resource in the same way [11]

6) Source 6: eNB randomly allocates sub-band resources which are not occupied to UEs

7) Source 7: Choose resources randomly in time and frequency domain

8) Source 8: Location-based resource partitioning and random resource allocation. For location based subset of subframes are mapped to a set of locations. UEs within that set of location transmit only on the subset of the subframes. Within each subset of subframes SA+DATA transmissions are adjacent in frequency and occupy random resources.

9) Source 9:

A. Scenario#1, #2: TDM of SA and Data Pools, PSCCH with UE-specific transmission cycle: 2 random TTIs out of 8 upcoming PSCCH subframes; PSSCH with UE-specific transmission cycle, 4 TTIs out of 32 upcoming PSSCH subframes, Random time offset within T-RPT subframes [12]

B. Scenario#3, #4: TDM of SA and Data Pools, PSCCH/PSSCH 8SFs/32SFs, Random time offset within T-RPT subframes [13], Spatial reuse over even/odd PSCCH/PSSCH period according to [14]

10) Source 10:

A. Scenario#1, #2: TDM of SA and Data Pools, PSCCH with UE-specific transmission cycle: 2 random TTIs out of 8 upcoming PSCCH subframes; PSSCH with UE-specific transmission cycle, 4 TTIs out of 32 upcoming PSSCH subframes, fully randomized T-RPT pattern [12]

B. Scenario#3, #4: TDM of SA and Data Pools, PSCCH/PSSCH 16SFs/64SFs, Random time offset within T-RPT subframes [13], Spatial reuse over even/odd PSCCH/PSSCH period according to [14]

11) Source 11: Random scheduling (2 sub-frames out of 32 sub-frames for a MAC PDU). Frequency hopping enabled.

12) Source 12: Random resource selection [16]

– Event-triggered traffic scenario

Description	Source 12	Source 13	Source 14	Source 15	Source 16	Source 17

		Sceanrio#1	Sceanrio#1	Sceanrio#1	Sceanrio#1	Sceanrio#1	Sceanrio#1
Carrier frequency (GHz)		6	6	6	6	6	6
Number of carriers (1 carrier is baseline)		1 (10 MHz)	1 (10 MHz)	1	1	1	1
Periodic scenario (e.g., periodic off, scenario#1..)		Periodic on,scenario#1	Periodic off,scenario#1	Scenario#1	Scenario#1	Scenario#1	Scenario#1
Number of subframes used to transmit each message	**190 bytes**	4 (2 control + 2 data)	4 (2 control + 2 data)	2 control + 2 data	2 control + 2 data	2 control + 2 data	2 control + 2 data
	300 bytes	4 (2 control + 2 data)	4 (2 control + 2 data)	2 control + 2 data	2 control + 2 data	2 control + 2 data	2 control + 2 data
	800 bytes	4 (2 control + 2 data)	4 (2 control + 2 data)	2 control + 2 data	2 control + 2 data	2 control + 2 data	2 control + 2 data
Number of RBs used to transmit each message in each subframe	**190 bytes**	50RBs	–	12RBs	12RBs	12RBs	12RBs
	300 bytes	50RBs	–	25RBs	25RBs	25RBs	25RBs
	800 bytes	50RBs	50RBs	50RBs	50RBs	50RBs	50RBs
Modulation	**190 bytes**	QPSK	–	QPSK	QPSK	QPSK	QPSK
	300 bytes	QPSK	–	QPSK	QPSK	QPSK	QPSK
	800 bytes	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK

Transmission power (in case of non-zero MPR, actual power after applying MPR)	23dBm	23dBm	23dBm	23dBm	23dBm	23dBm
Physical channel format (e.g., number of RS symbols)	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data	4 RS symbols	4 RS symbols	4 RS symbols	4 RS symbols
MPR and inband emission model	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	Not modelled	Not modelled	Not modelled	Not modelled
Synchronization assumptions	Ideal time synchronization and frequency offset	Ideal time synchronization and frequency offset	Time: ideal, Frequency: +/- 0.1PPM	Time: ideal, Frequency: +/- 0.1PPM	Time: ideal, Frequency: +/- 0.1PPM	Time: ideal, Frequency: +/- 0.1PPM
SA assumption (e.g., SA overhead)	Control channel occupy 20% of the SA Period,SA and Data is TDM(e.g., Control channel occupy 8 ms when SA Period is 40ms)	Control channel occupy 20% of the SA Period,SA and Data is TDM(e.g., Control channel occupy 8 ms when SA Period is 40ms)	59 bit	59 bit	59 bit	59 bit
Detailed assumptions for event-triggered traffic (e.g., event probability)	Average waiting time is 1s per Packet	Average waiting time is 1s per Packet	X = 0.01	X = 0.01	X = 0.01	X = 0.01
Remark	–	–	–	–	–	–

It is further noted that resource allocation principles used by sources are different and are summarized below:

1) Source 12: Random resource selection [16]

2) Source 13: Random resource selection [16]

3) Source 14: Random resource selection for periodical messages and emergency triggered messages; 2 blind retransmissions for emergency triggered messages [15]

4) Source 15: Random resource selection for periodical messages and cooperative retransmission for emergency triggered messages; 2 blind retransmissions for emergency triggered messages [15]

5) Source 16: Random resource selection for periodical messages and emergency triggered messages; 4 blind restransmission for emergency triggered messages [15]

6) Source 17: Random resource selection for periodical messages and cooperative retransmission for emergency triggered messages;4 blind restransmission for emergency triggered messages [15]

B.2 Simulation results

Maximum coupling loss (MCL) of each source is as follows:

– Periodic traffic scenario

Description	Message size (Byte)	Scenario#1	Scenario#2	Scenario#3	Scenario#4	Scenario#5
Source 1	190	130.01 for NLOS	129.87 for NLOS	129.87 for NLOS	129.37 for NLOS	129.37 for NLOS
	300	129.95 for NLOS	129.89 for NLOS	129.89 for NLOS	129.55 for NLOS	129.55 for NLOS
Source 2	190	130.01 for NLOS	129.87 for NLOS	129.87 for NLOS	129.37 for NLOS	–
	300	129.95 for NLOS	129.89 for NLOS	129.89 for NLOS	129.55 for NLOS	–
Source 3	190	128.14 for NLOS	129.24 for NLOS	129.24 for LOS 124.69 for NLOS	–	–
	300	127.22 for NLOS	127.75 for NLOS	127.75 for LOS 122.51 for NLOS	–	–
Source 4	190	125.3 for NLOS	125.7 for NLOS	125.7 for NLOS	126.2 for NLOS	–
	300	122 for NLOS	122.7 for NLOS	122.7 for NLOS	123.2 for NLOS	–
Source 5	190	125.3 for NLOS	125.7 for NLOS	125.7 for NLOS	126.2 for NLOS	–
	300	122 for NLOS	122.7 for NLOS	122.7 for NLOS	123.2 for NLOS	–
Source 6	190	124.2 for NLOS	124.8 for NLOS	125.2 for NLOS	125 for NLOS	125 for NLOS
	300	123.6 for NLOS	123.5 for NLOS	123.7 for NLOS	123.6 for NLOS	123.6 for NLOS
Source 7	190	124.2 for NLOS	124.8 for NLOS	125.2 for NLOS	125 for NLOS	125 for NLOS
	300	123.6 for NLOS	123.5 for NLOS	123.7 for NLOS	123.6 for NLOS	123.6 for NLOS
Source 8	190	132.70 for NLOS	133.90 for NLOS	133.32 for NLOS	134.10 for NLOS	–
	300	130.9 for NLOS	132.10 for NLOS	132.15 for NLOS	132.40 for NLOS	–
Source 9	190	132 for NLOS	132.9 for NLOS	132.9 for NLOS	131.6 for NLOS	–
	300	130.4 for NLOS	130.6 for NLOS	130.6 for NLOS	130.2 for NLOS	–

Source 10	190	128.4 for NLOS	129.5 for NLOS	129.5 for NLOS	128.4 for NLOS	–
	300	127.1 for NLOS	127.5 for NLOS	127.5 for NLOS	127.1 for NLOS	–
Source 11	190	128.45 for NLOS	129.55 for NLOS	129.45 for NLOS	128.55 for NLOS	–
	300	127.15 for NLOS	126.65 for NLOS	126.55 for NLOS	126.35 for NLOS	–
Source 12	190	125.5 for NLOS	128.8 for NLOS	125.5 for NLOS	125.8 for NLOS	125.8 for NLOS
	300	124 for NLOS	126.7 for NLOS	124 for NLOS	123.8 for NLOS	123.8 for NLOS

– Event-triggered traffic scenario

Description	**Message size (Byte)**	**Scenario#1**	**Scenario#2**	**Scenario#3**	**Scenario#4**	**Scenario#5**
Source 12	190	125.5 for NLOS	–	–	–	–
	300	124 for NLOS	–	–	–	–
	800	115 for NLOS	–	–	–	–
Source 13	190	–	–	–	–	–
	300	–	–	–	–	–
	800	115 for NLOS	–	–	–	–
Source 14	190	122.66	–	–	–	–
	300	123.47	–	–	–	–
	800	116.46	–	–	–	–
Source 15	190	122.66	–	–	–	–
	300	123.47	–	–	–	–
	800	116.46	–	–	–	–
Source 16	190	122.66	–	–	–	–
	300	123.47	–	–	–	–
	800	119.26	–	–	–	–
Source 17	190	122.66	–	–	–	–
	300	123.47	–	–	–	–
	800	119.26	–	–	–	–

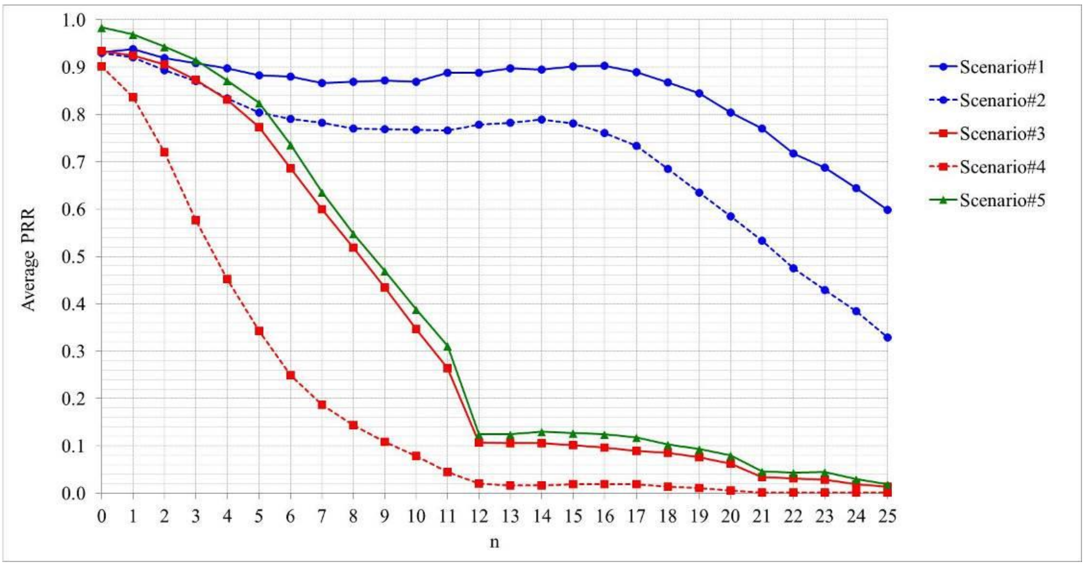
It is noted that MCL is calculated by the following equation:

MCL (dB) = maximum transmit power (dBm) + transmit antenna gain + receive antenna gain – (thermal noise density (dBm/Hz) + receiver noise figure (dB) + 10·log$_{10}$*(occupied channel bandwidth (Hz)) + required SINR (dB))*

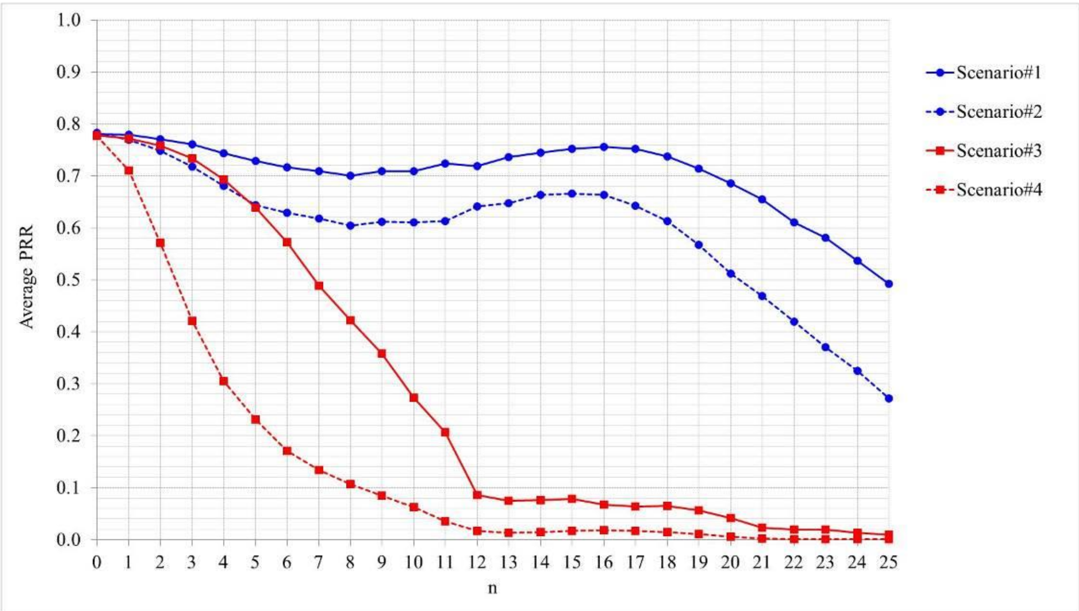
Average PRR of each source is as follows (a=n*20 m, b=(n+1)*20 m):

– Periodic traffic scenario

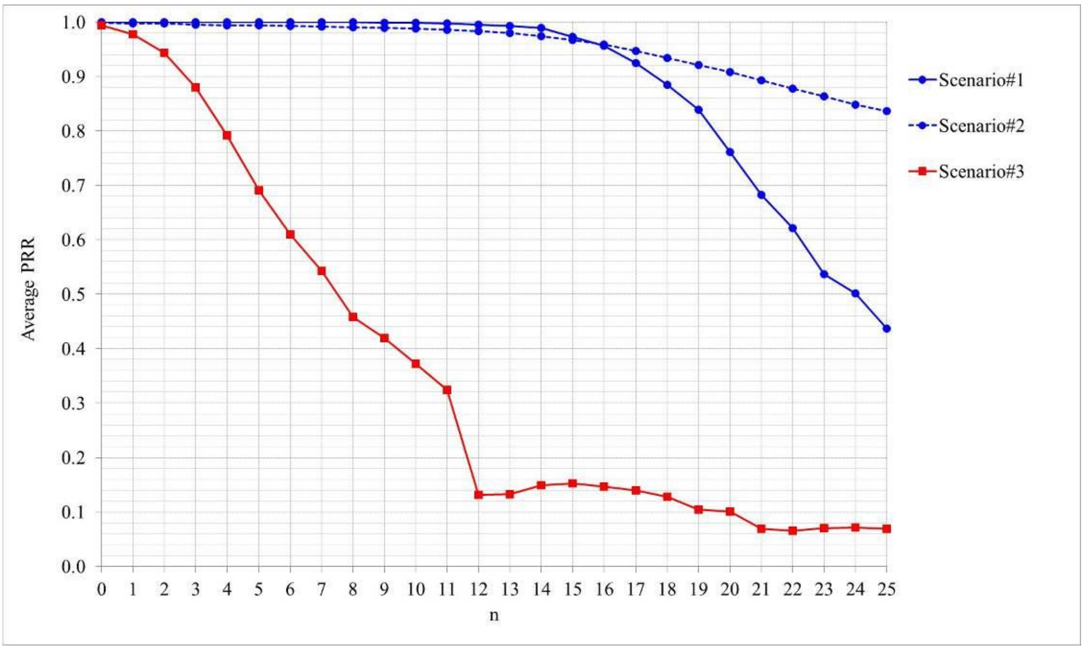
- Source 1



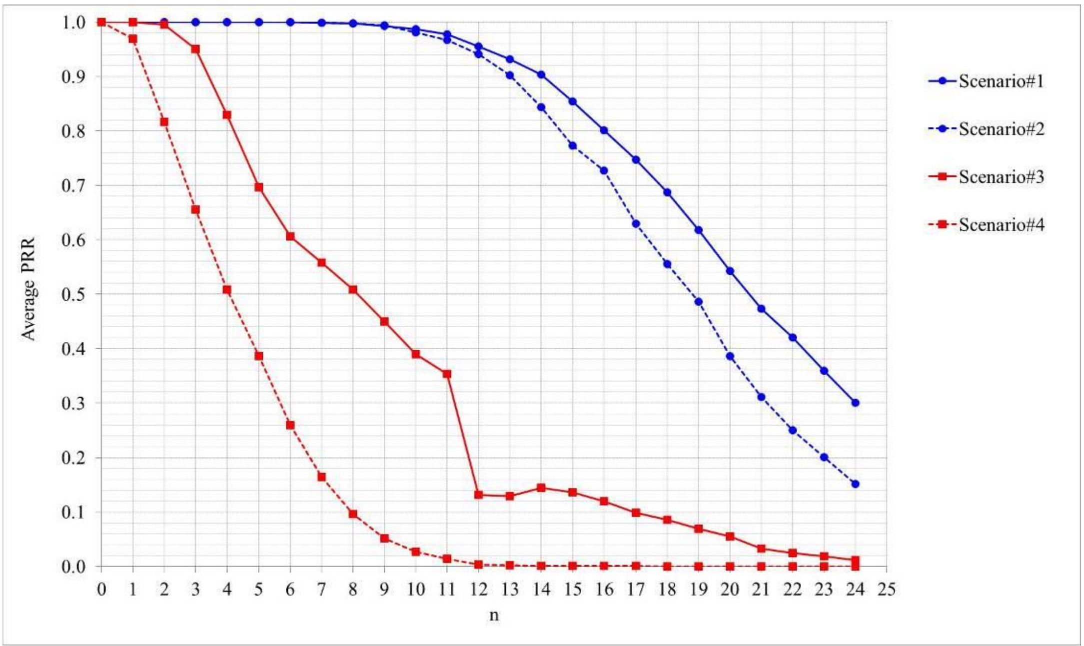
- Source 2



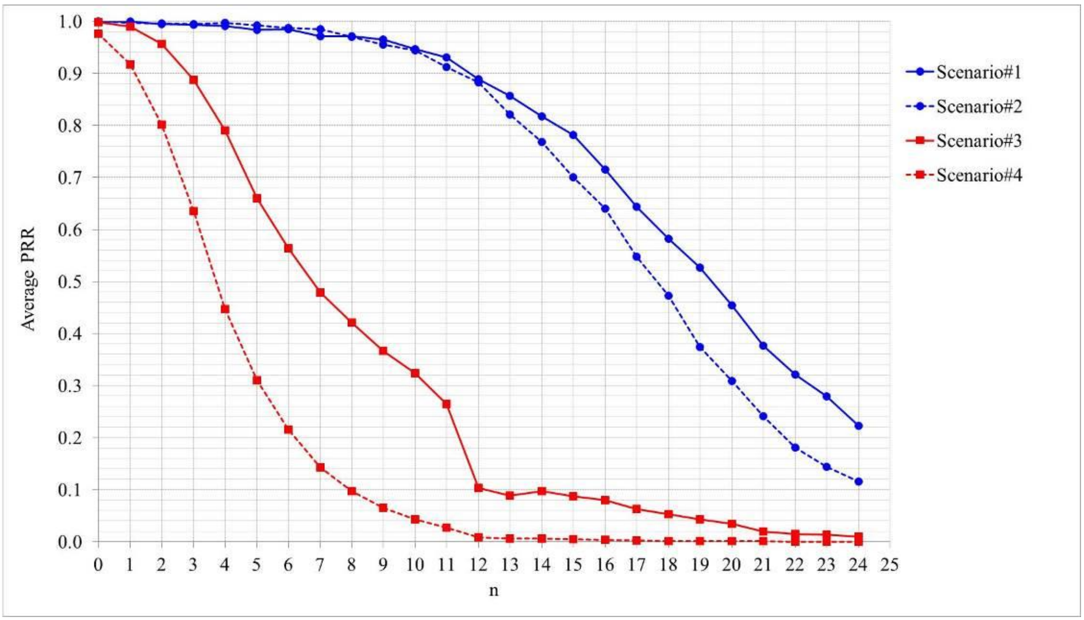
- Source 3



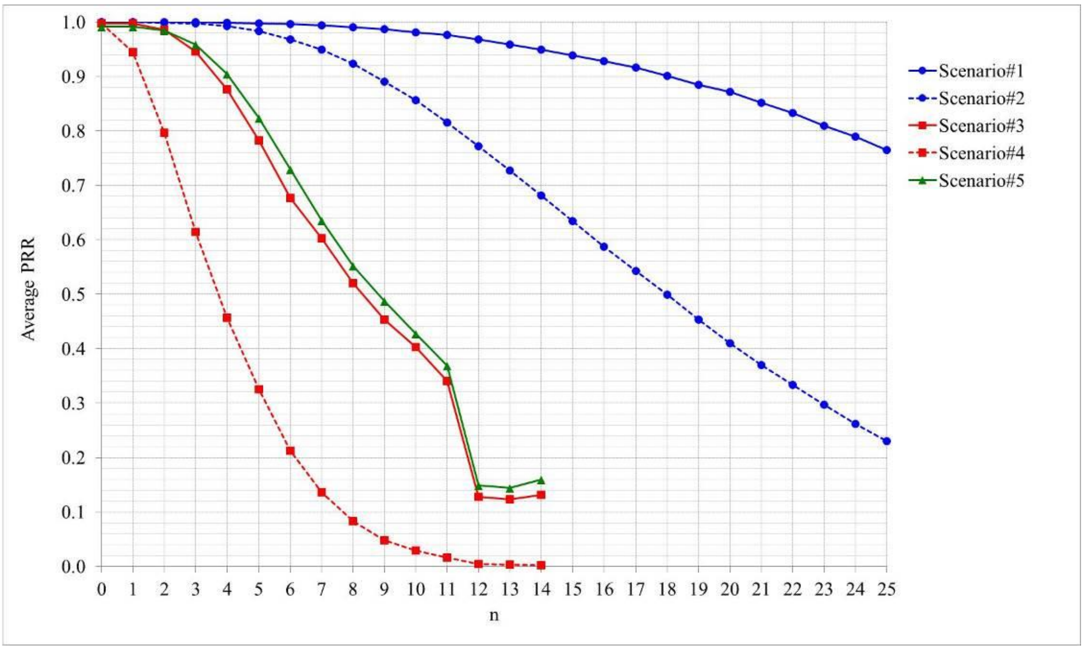
- Source 4



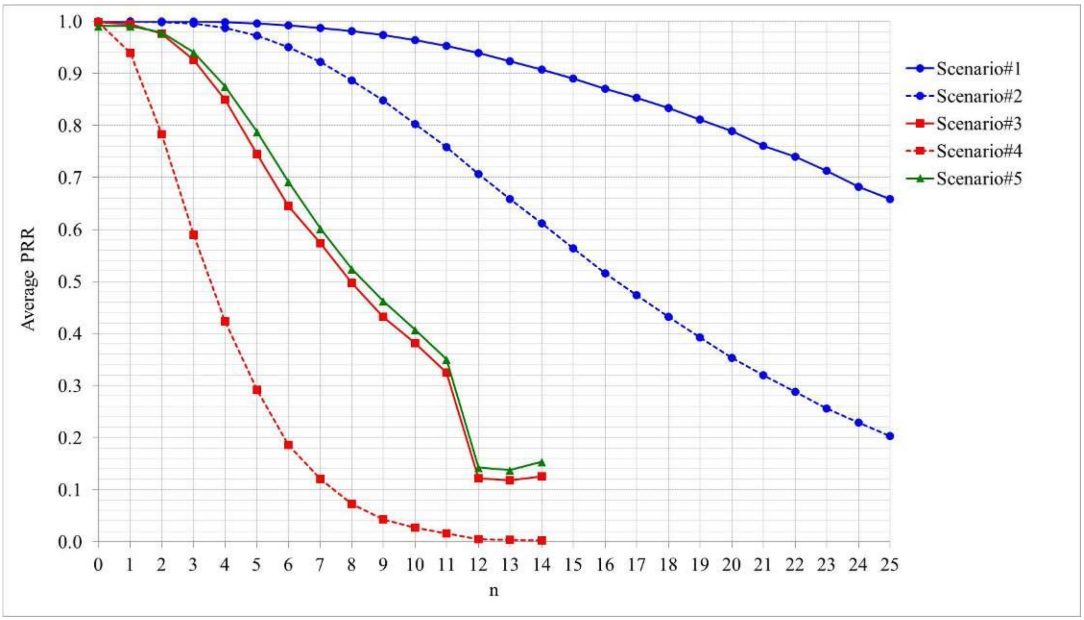
- Source 5



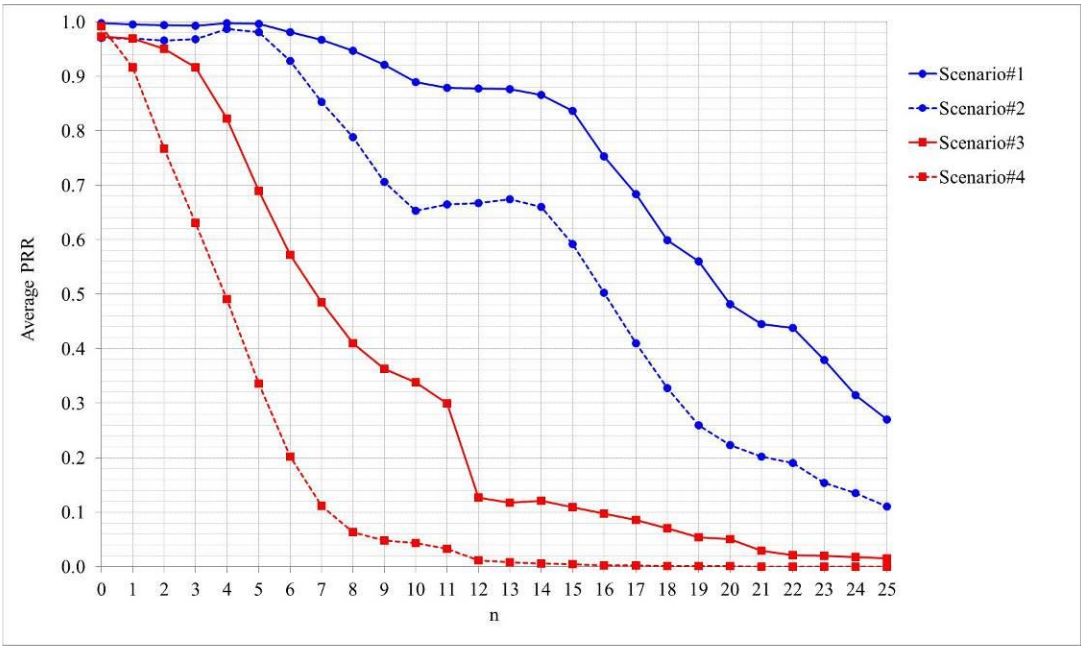
- Source 6



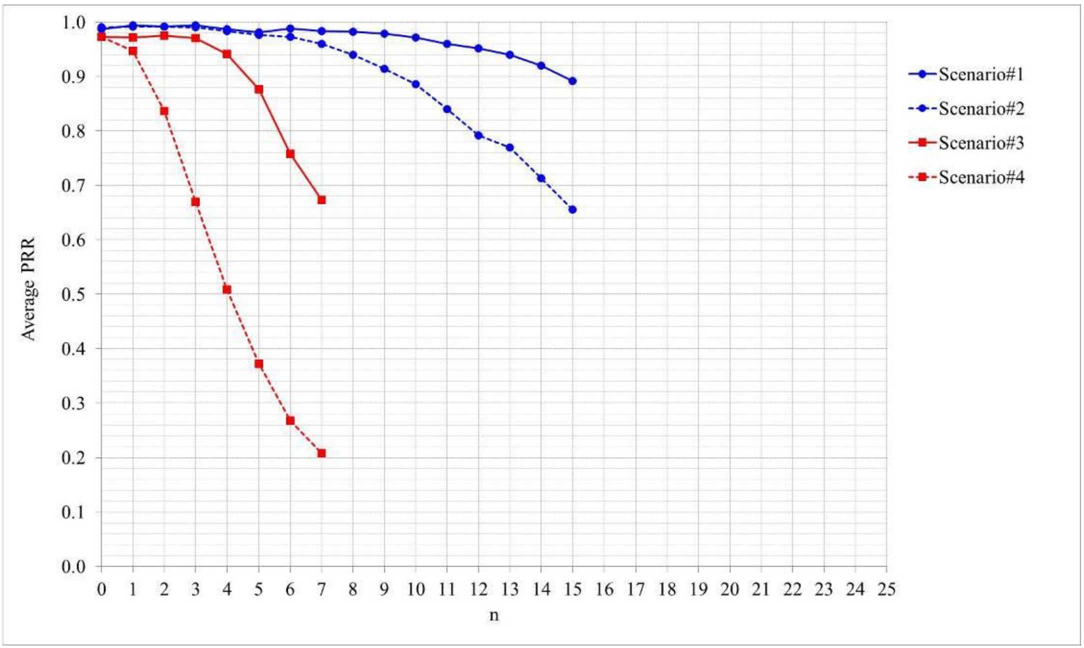
- Source 7



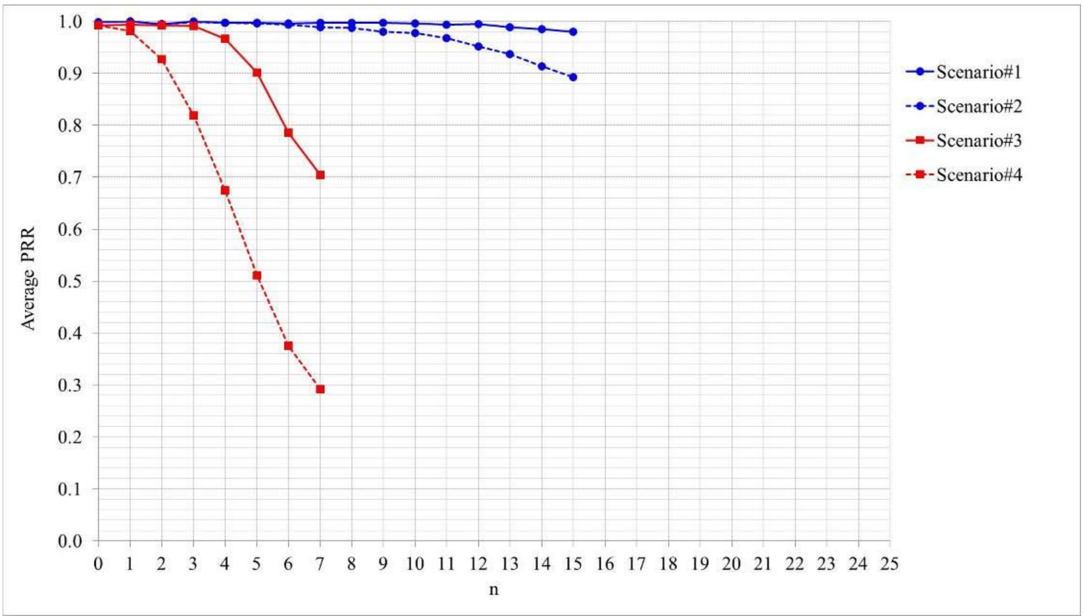
- Source 8



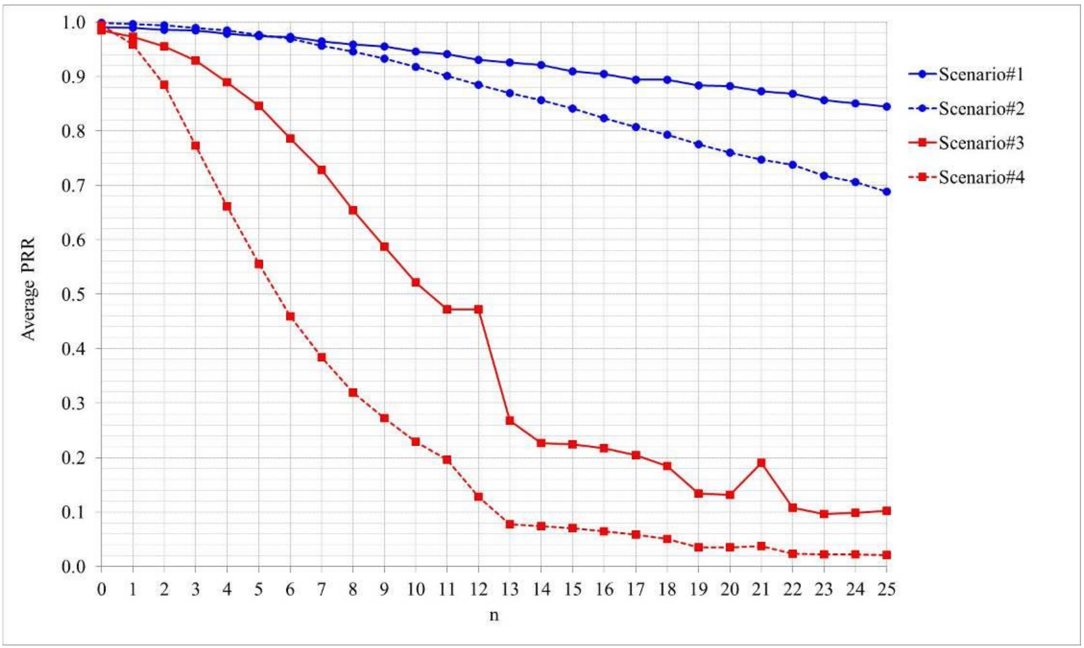
- Source 9



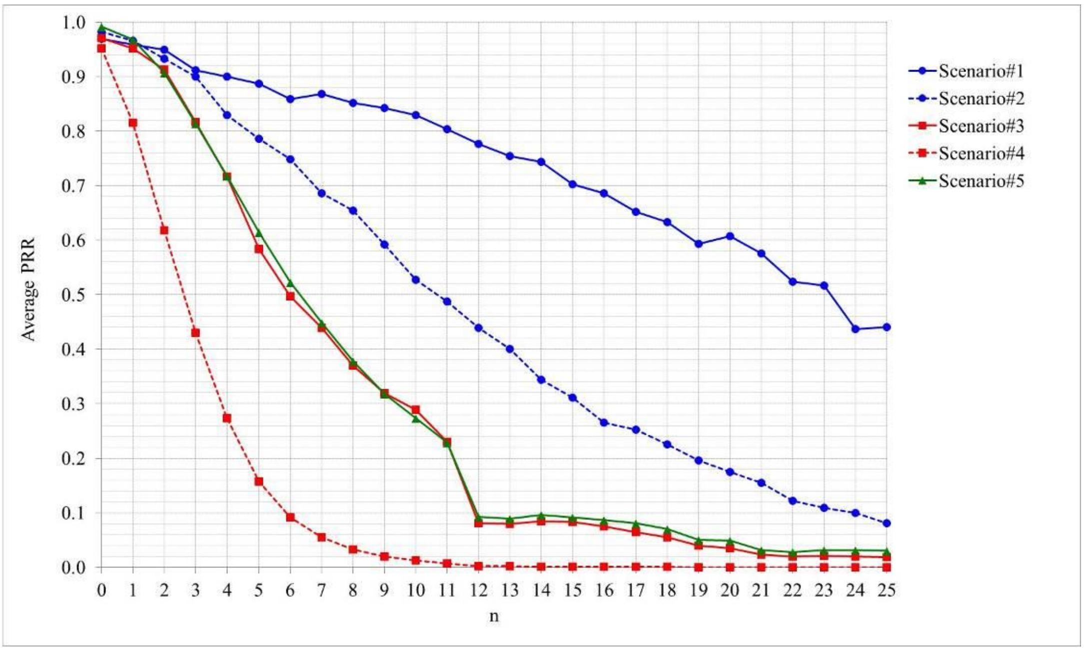
- Source 10



- Source 11

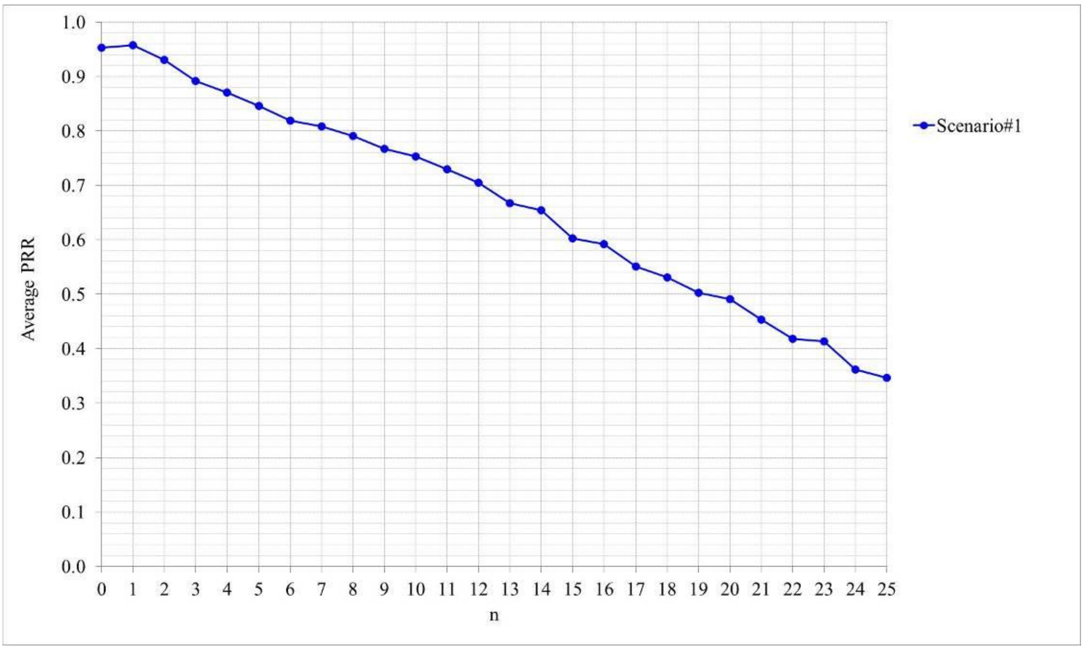


- Source 12

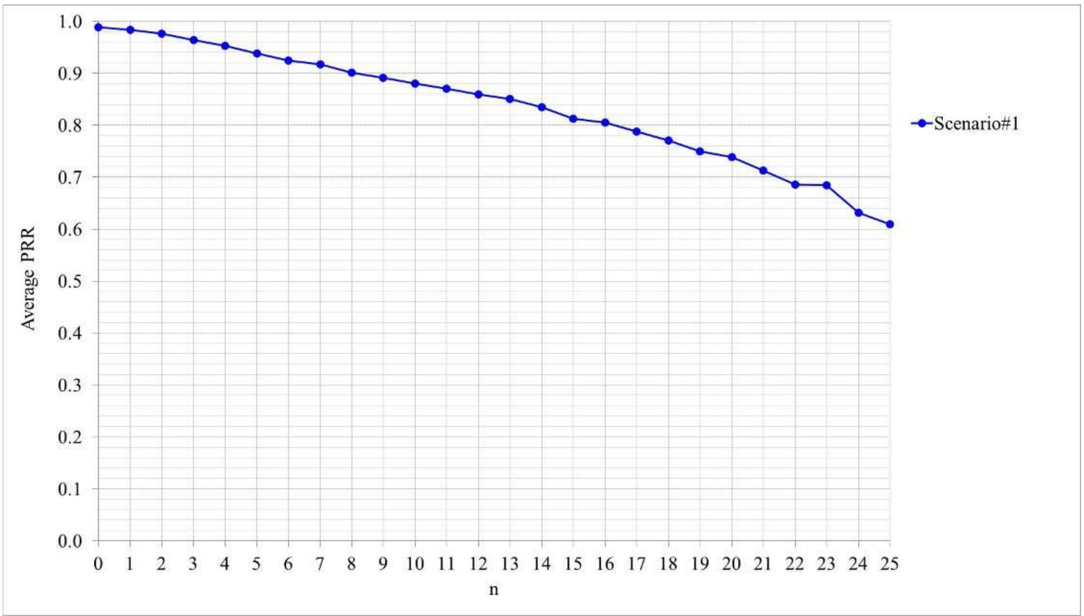


– Event-triggered traffic scenario

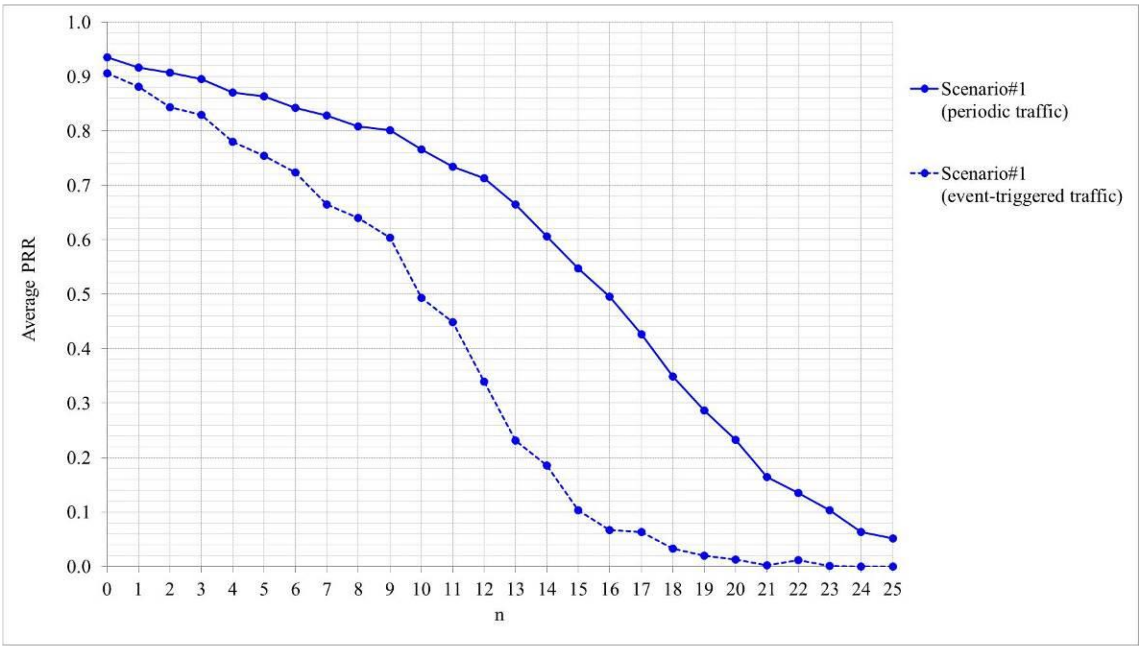
- Source 12



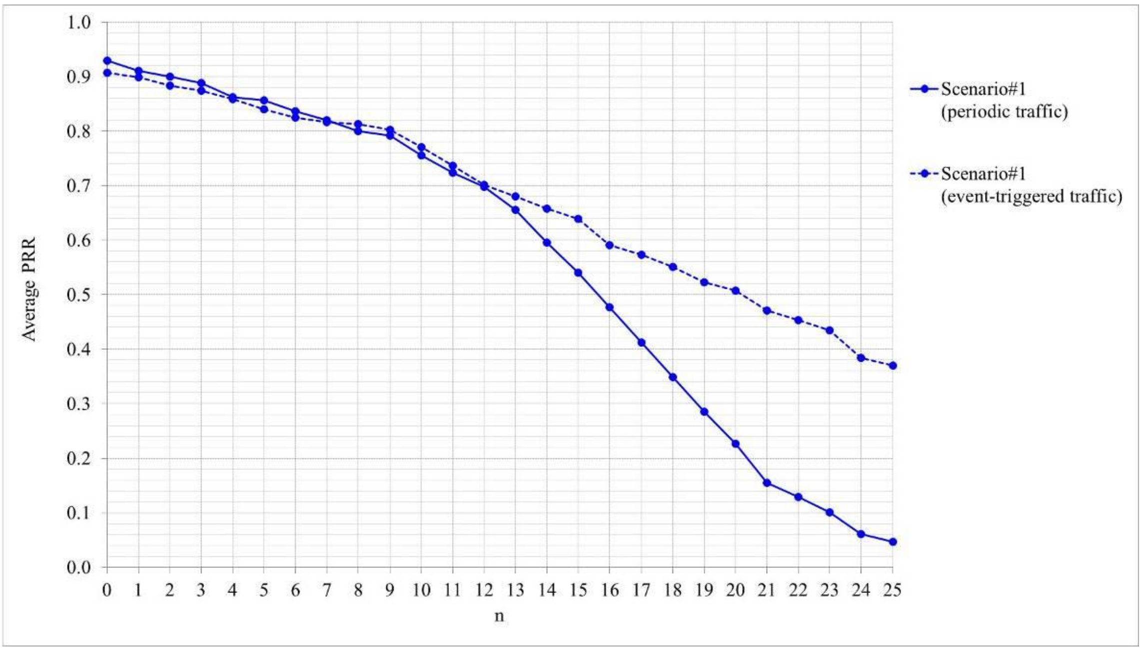
- Source 13



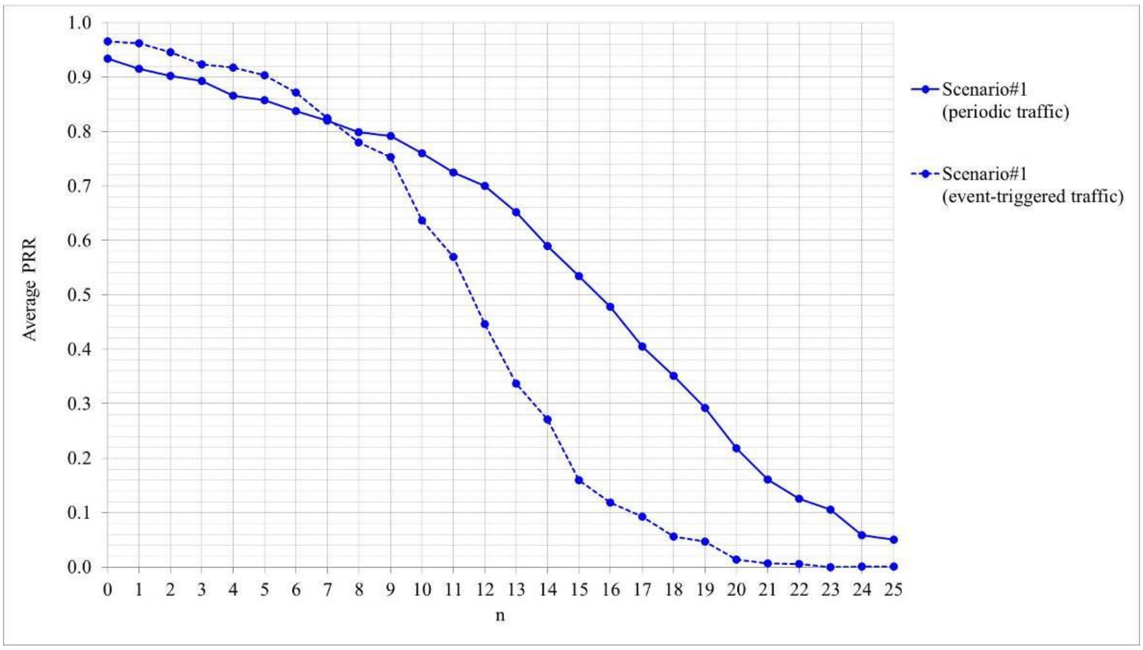
- Source 14



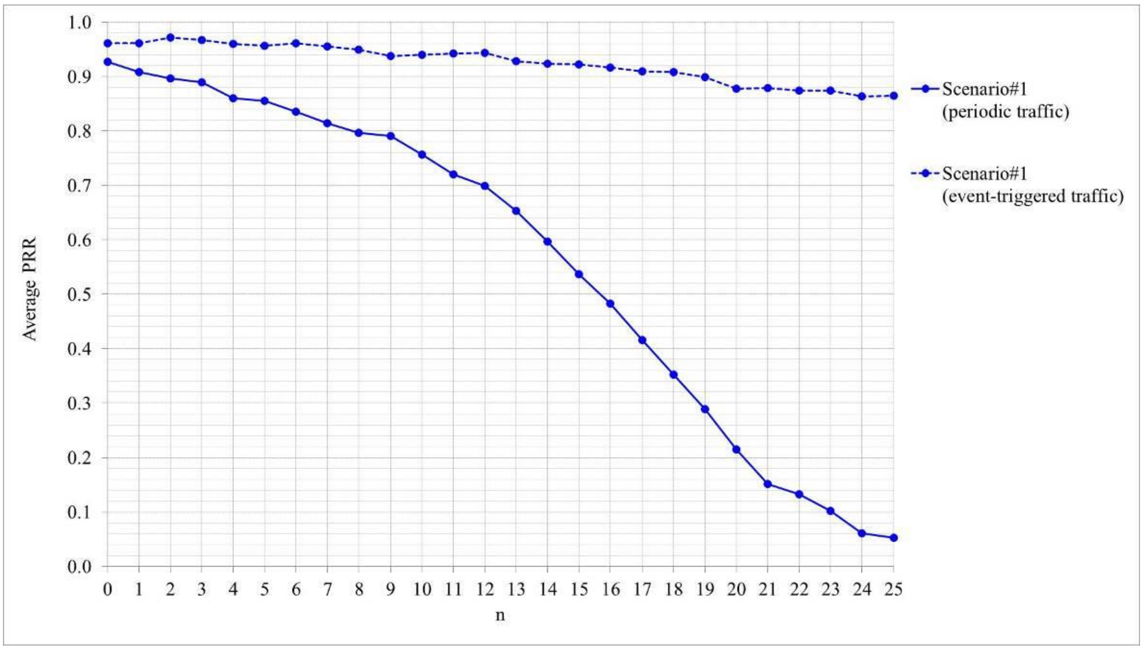
- Source 15



- Source 16



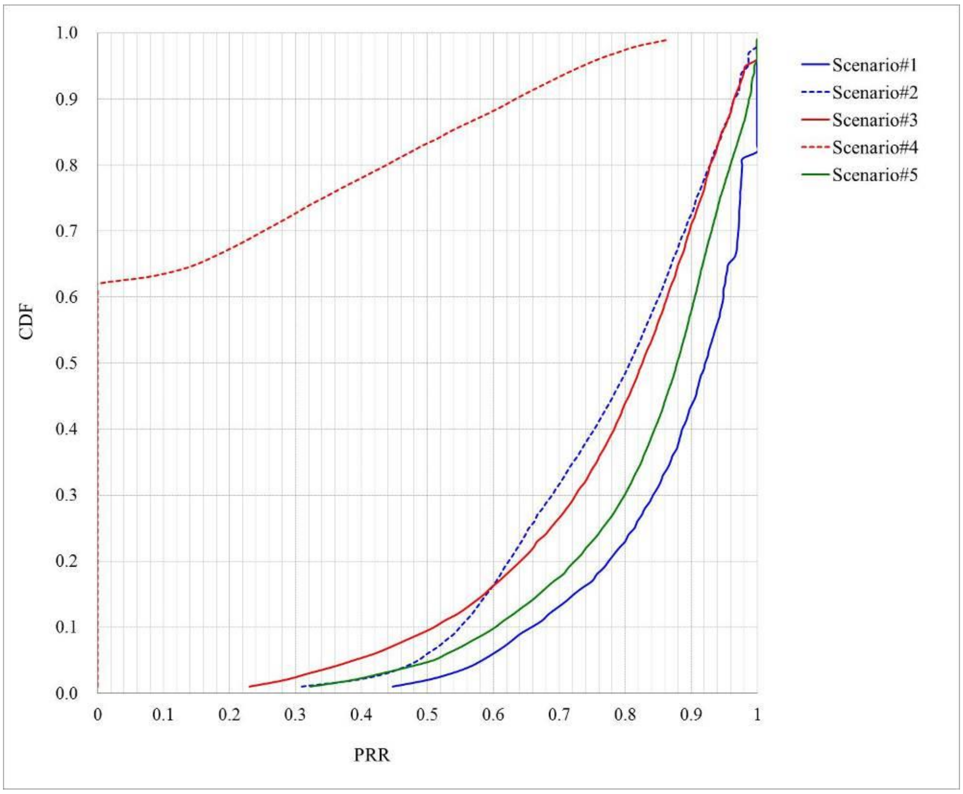
- Source 17



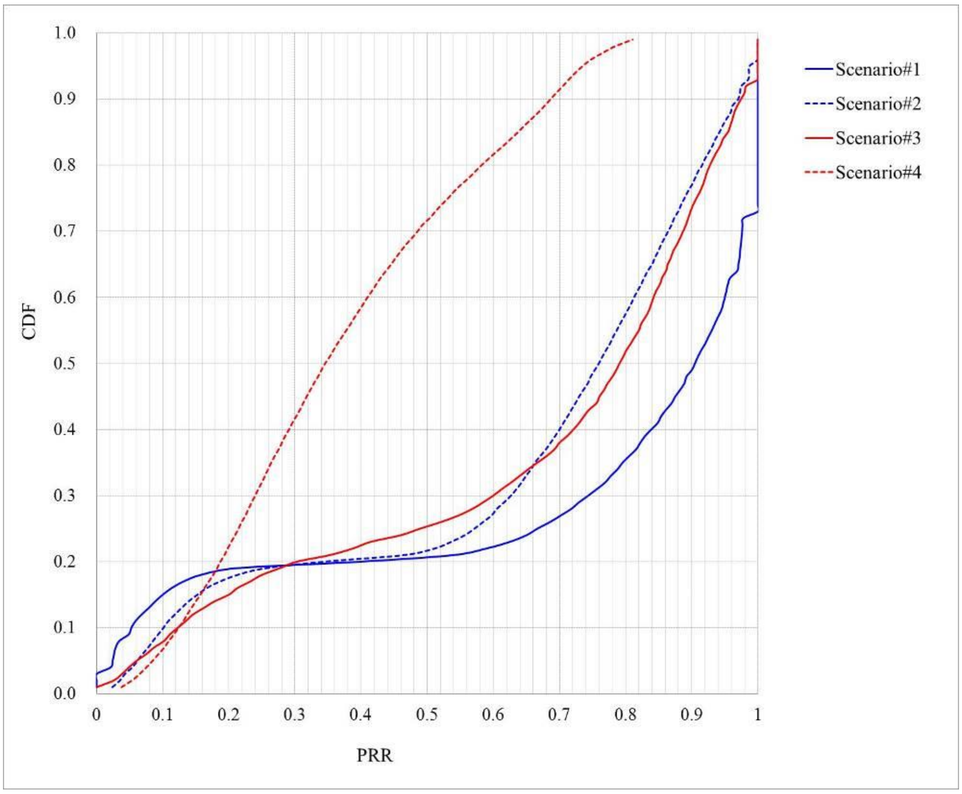
CDF of PRR of each source is as follows (a=0, b=320 m for scenario#1, #2 and b=150 m for scenario#3, #4, #5):

− Periodic traffic scenario

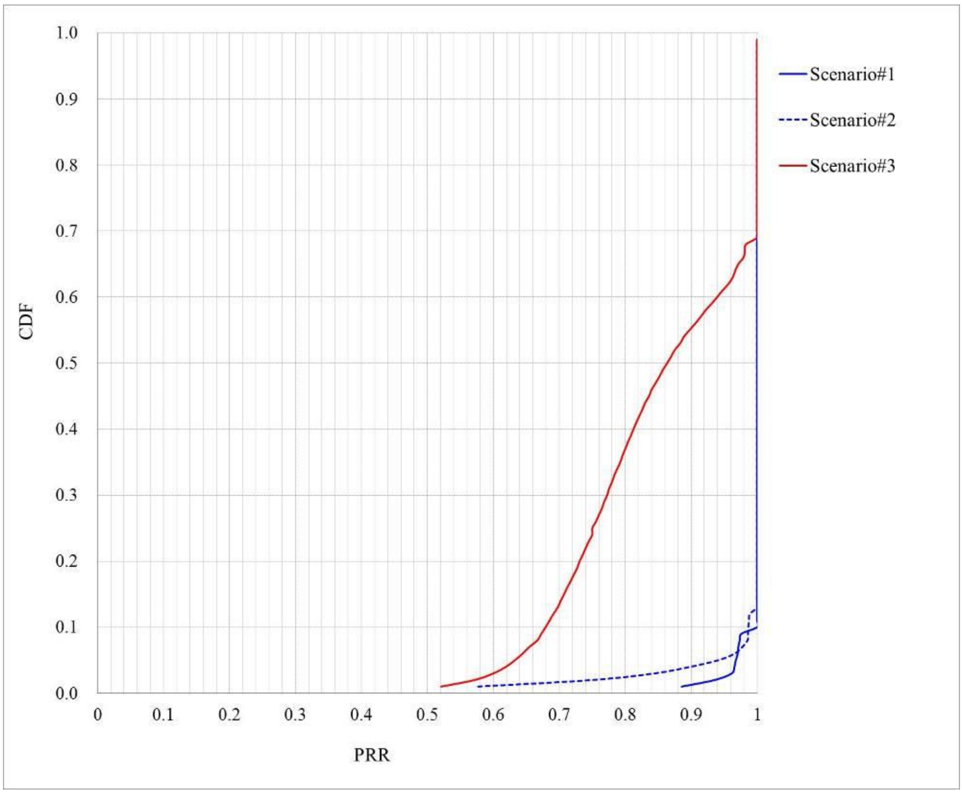
- Source 1



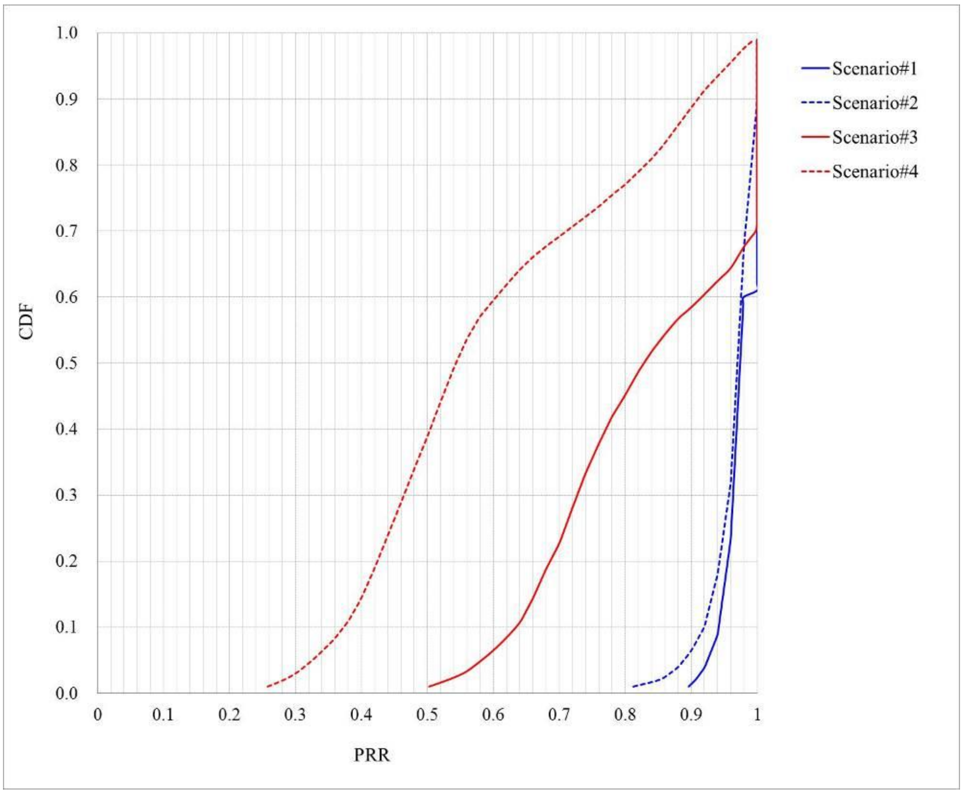
- Source 2



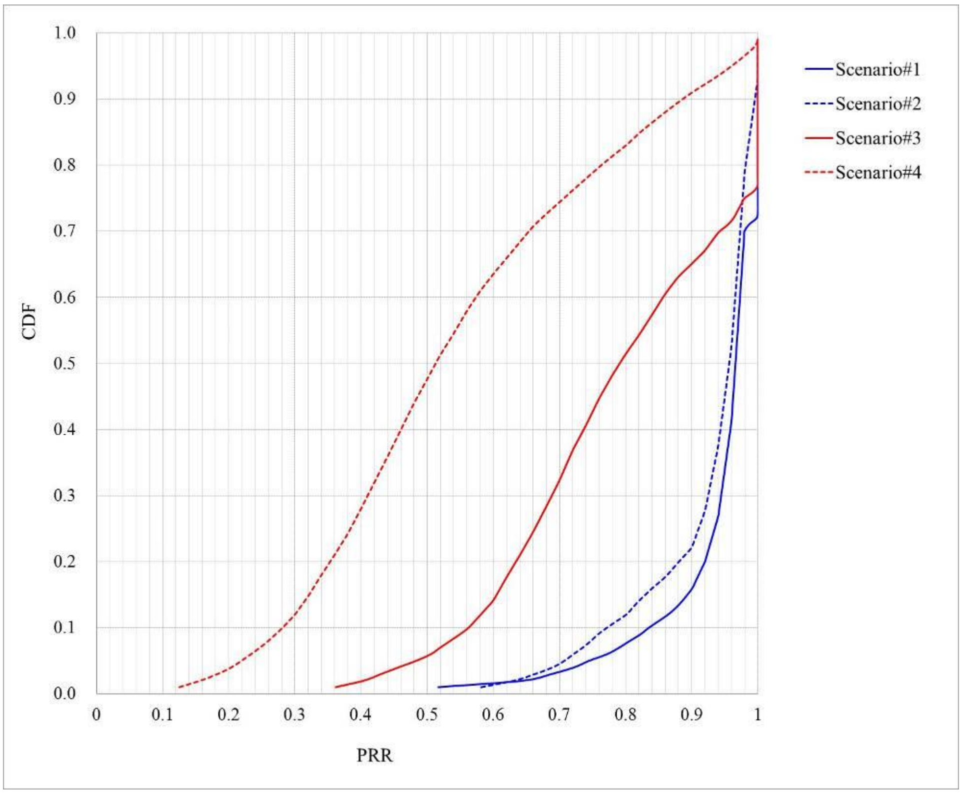
- Source 3



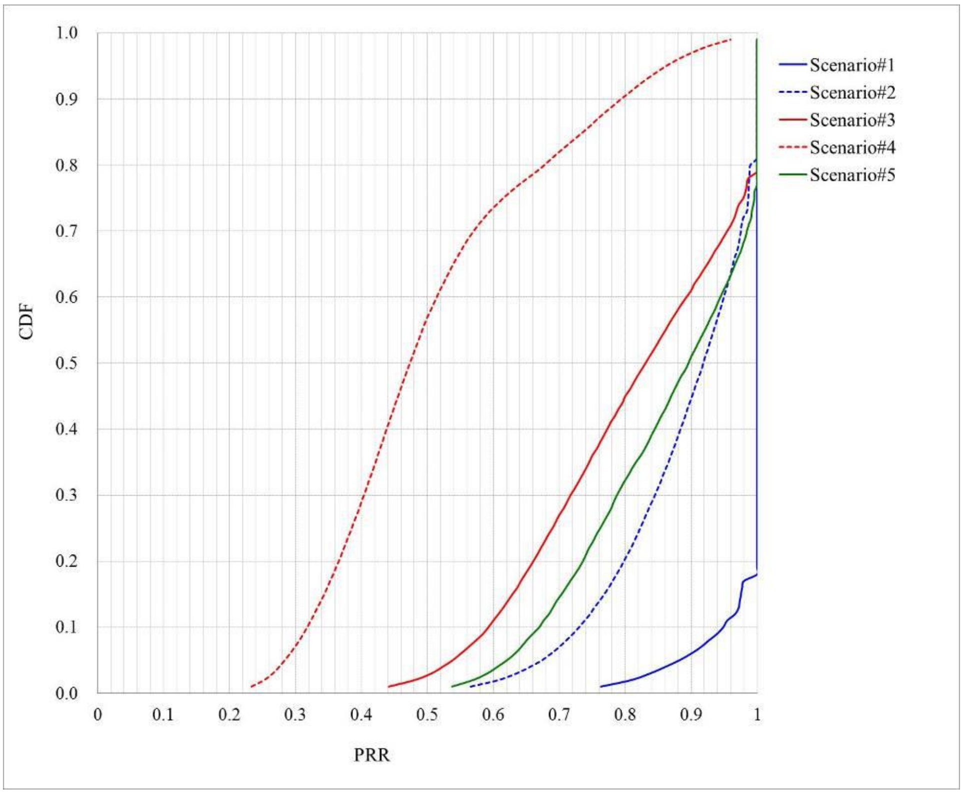
- Source 4



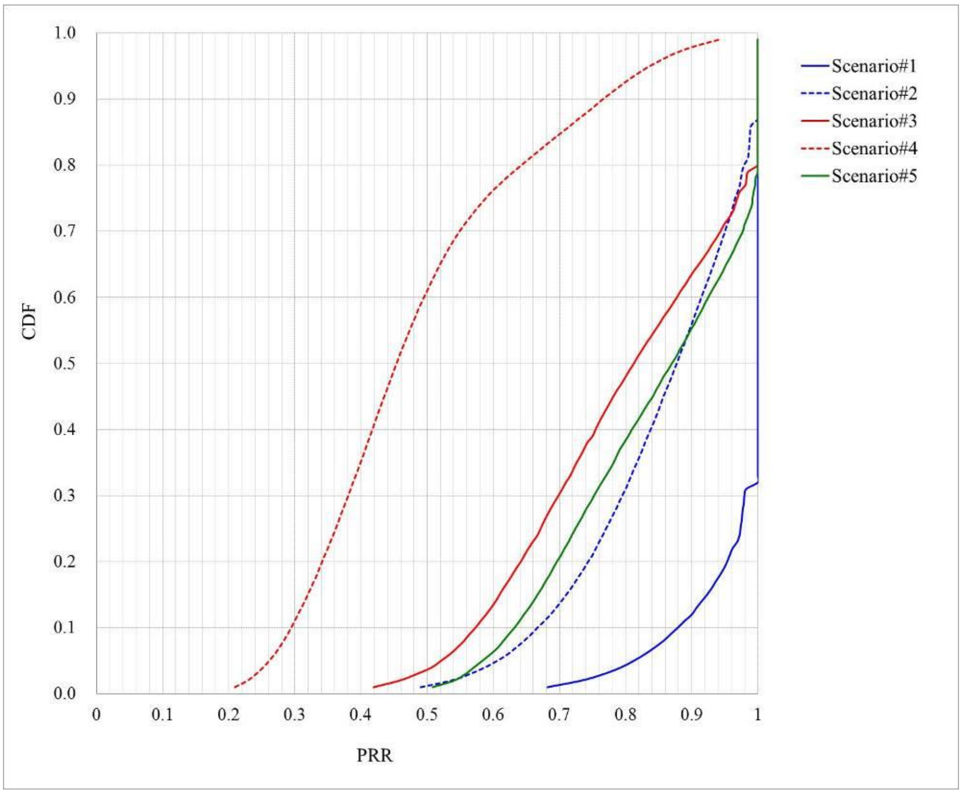
- Source 5



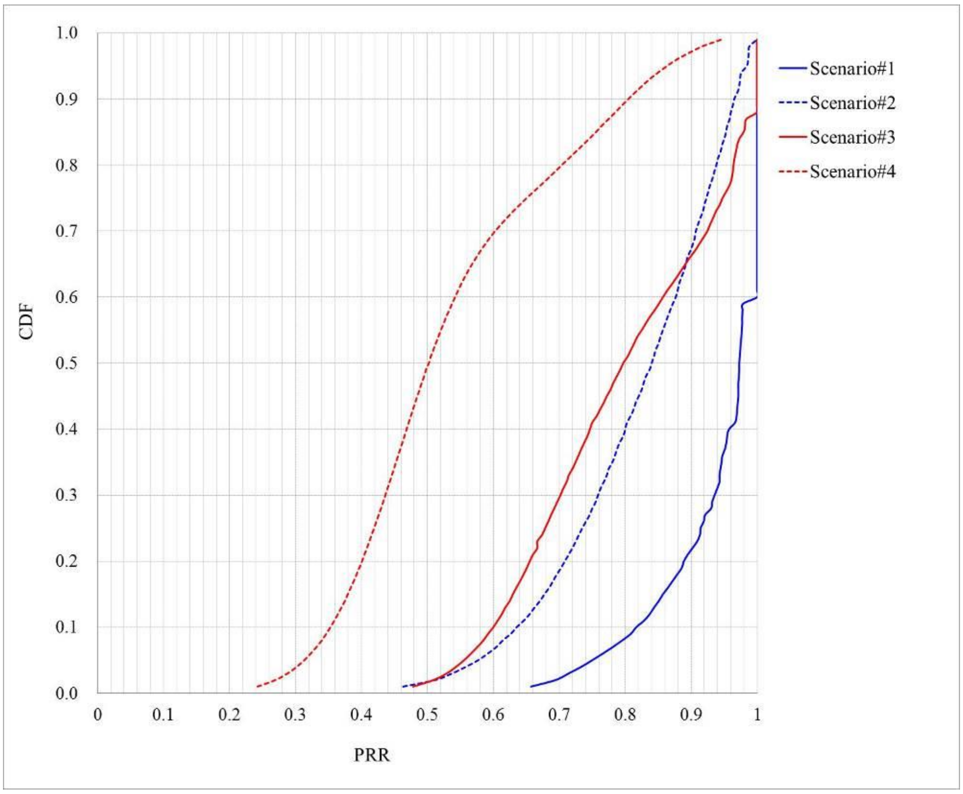
- Source 6



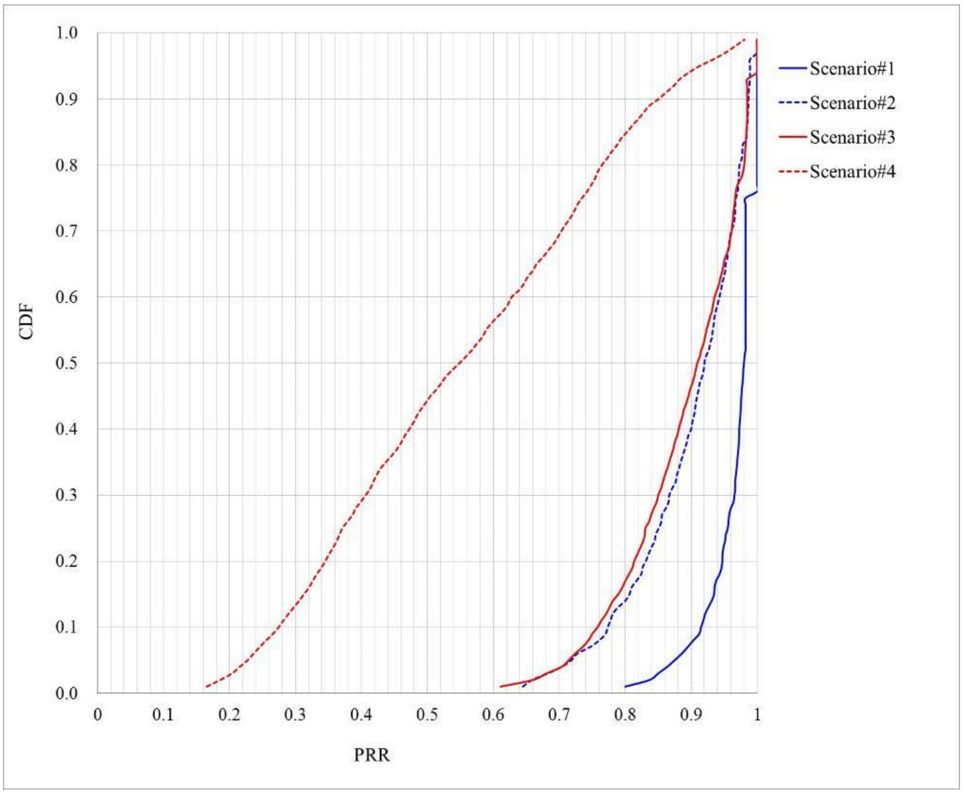
- Source 7



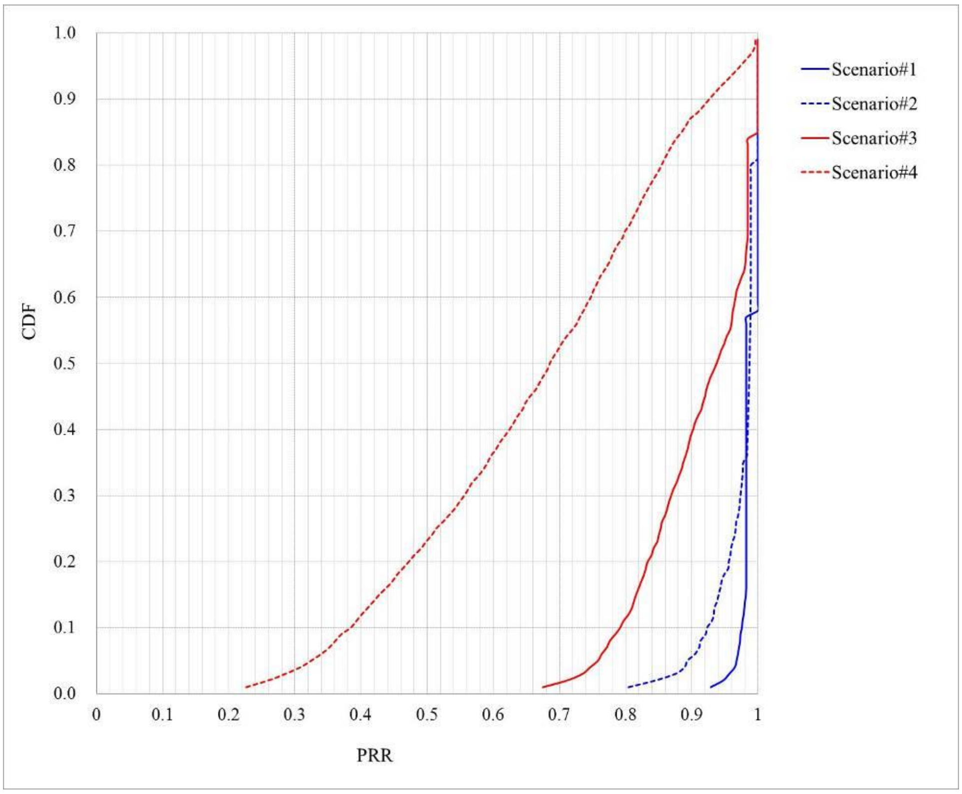
- Source 8



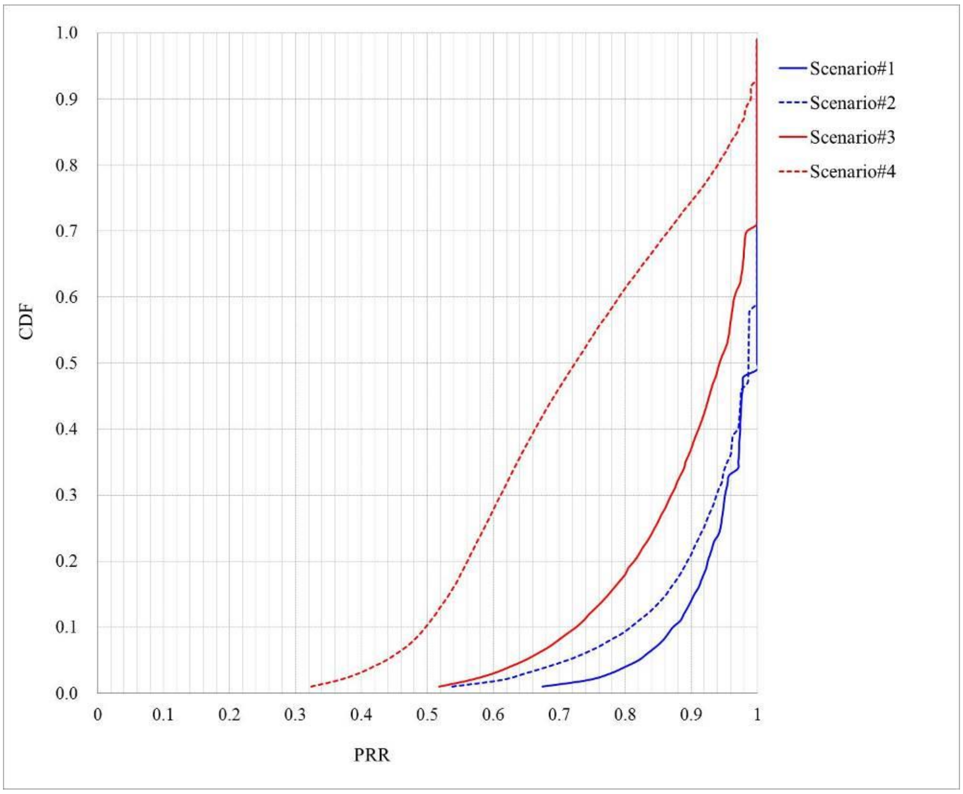
- Source 9



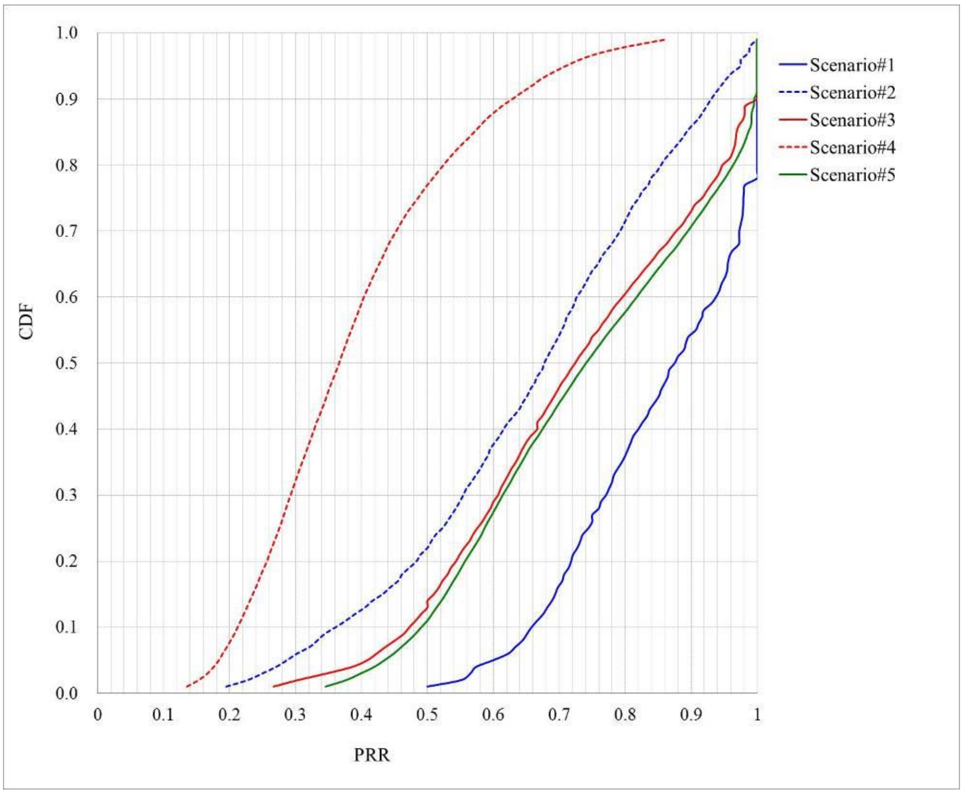
- Source 10



- Source 11

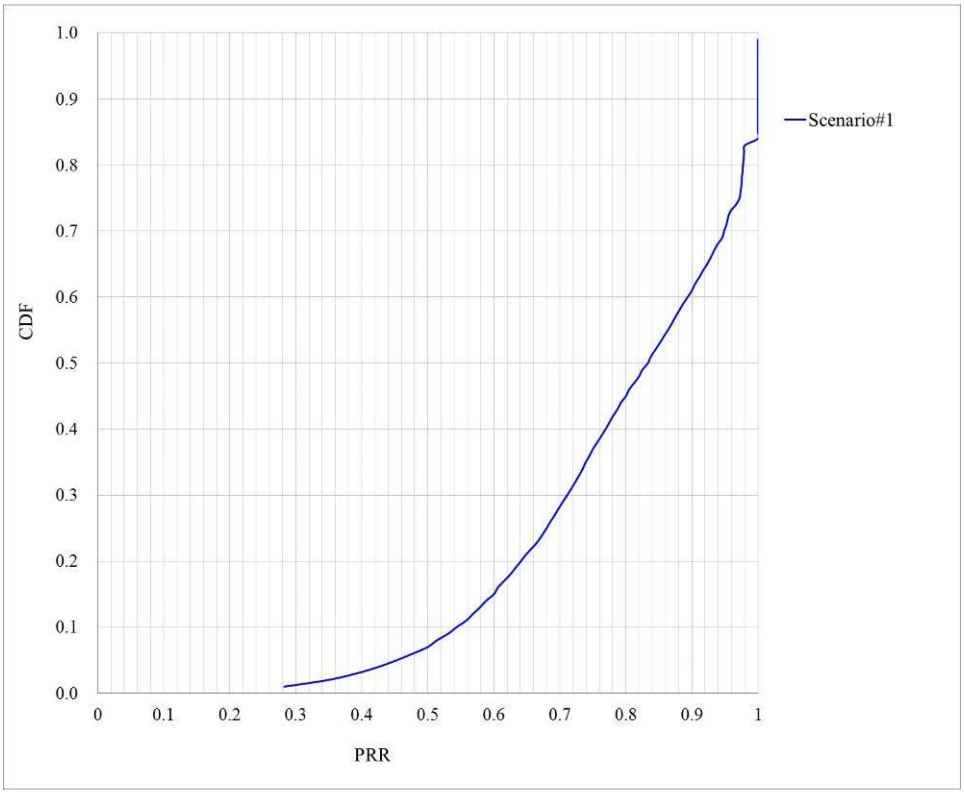


- Source 12

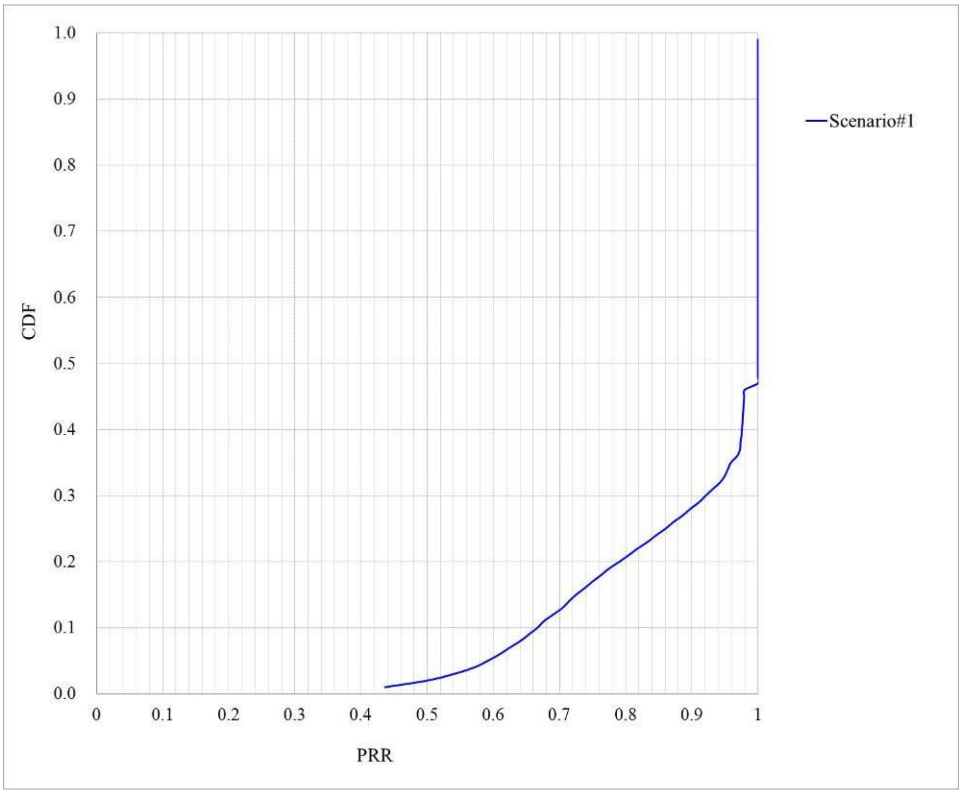


– Event-triggered traffic scenario

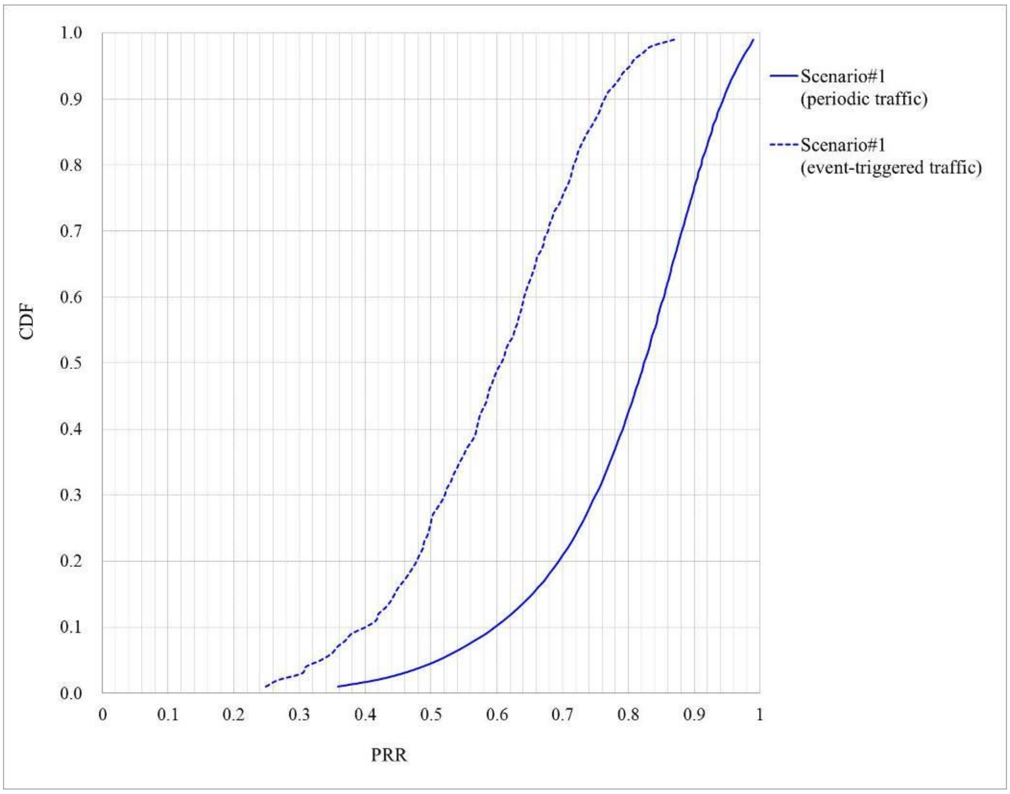
- Source 12



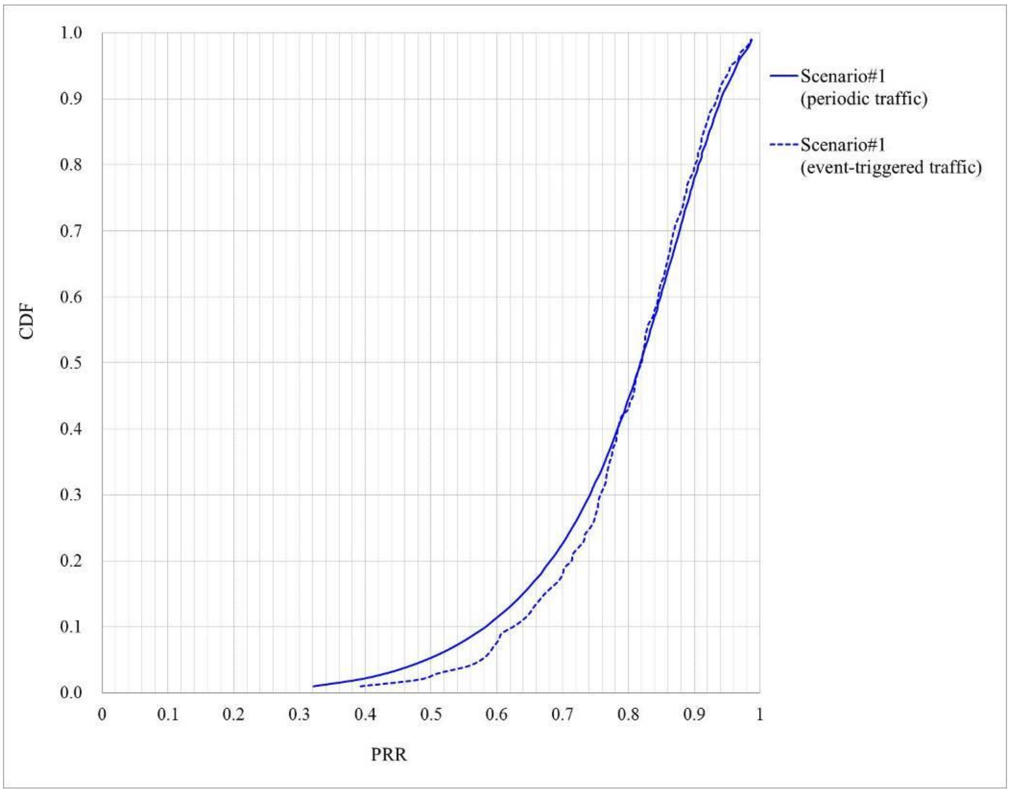
- Source 13



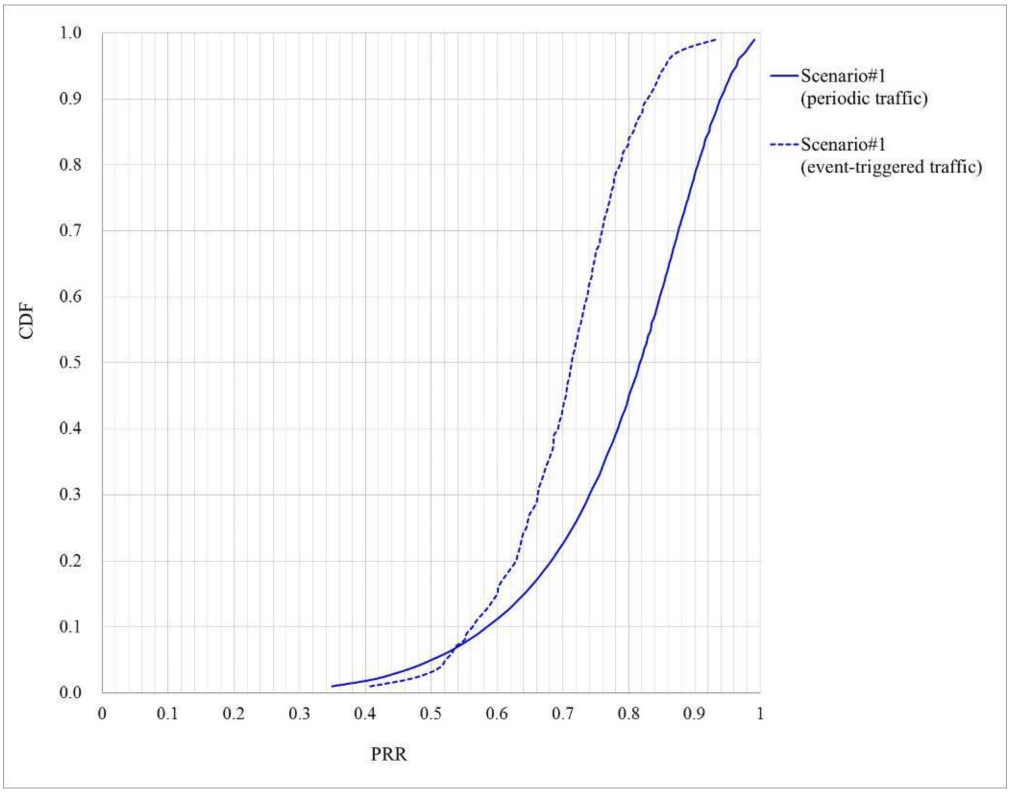
- Source 14



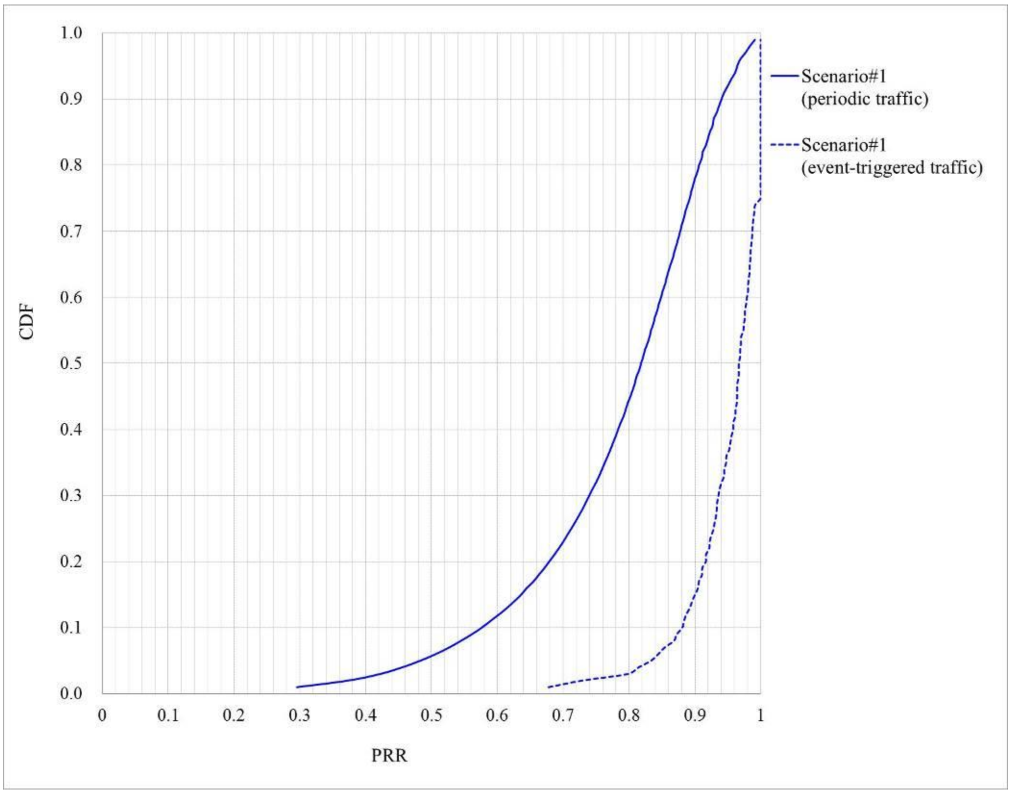
- Source 15



- Source 16



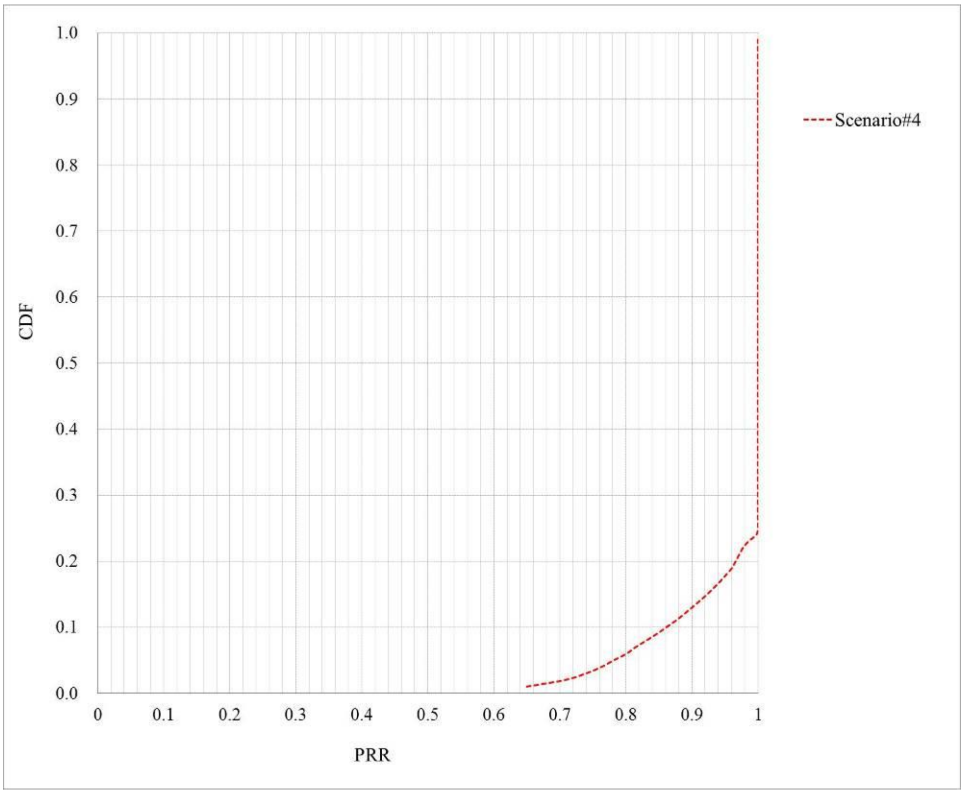
- Source 17



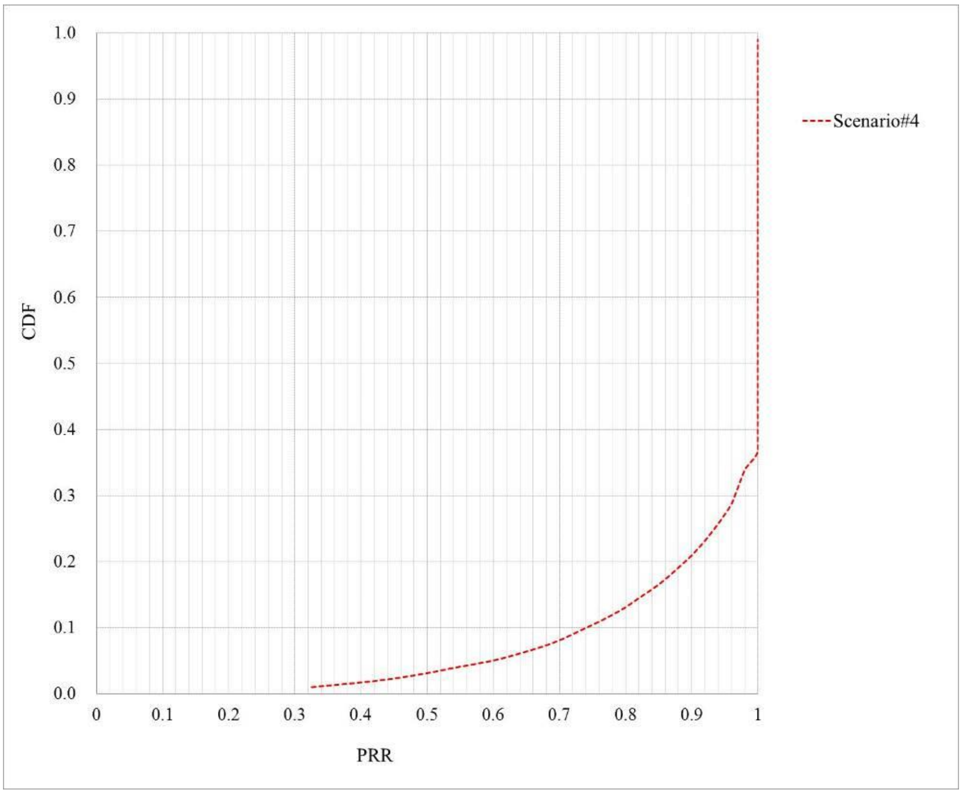
CDF of PRR of each source is as follows (a=0, b=50 m for scenario#4, #5):

– Periodic traffic scenario

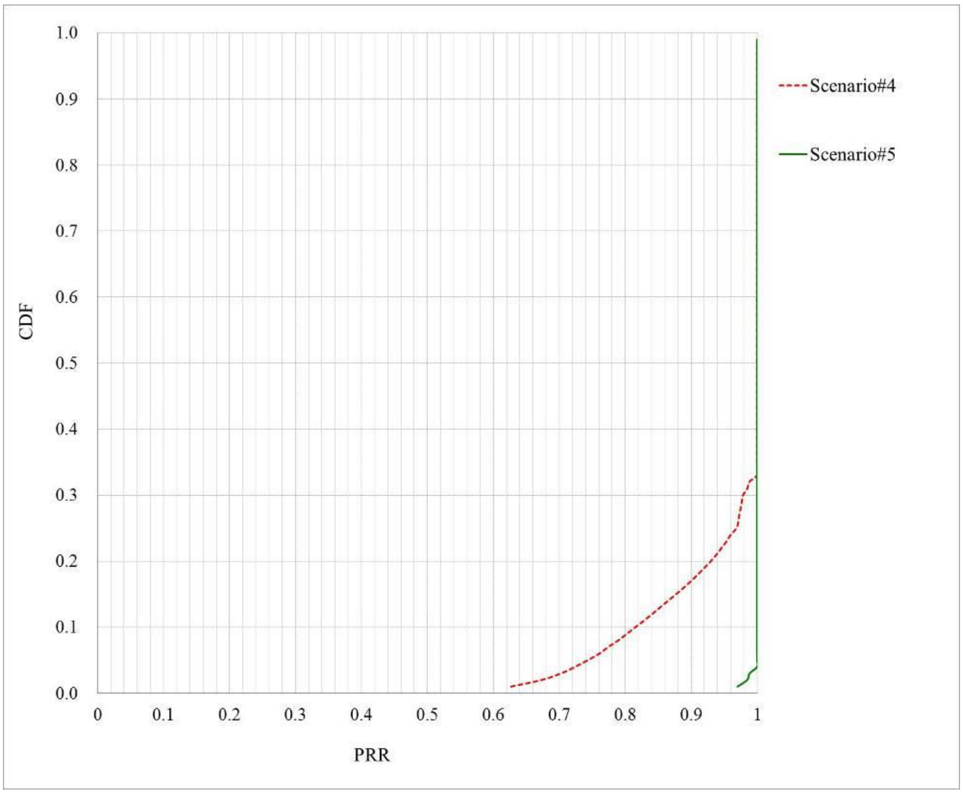
- Source 4



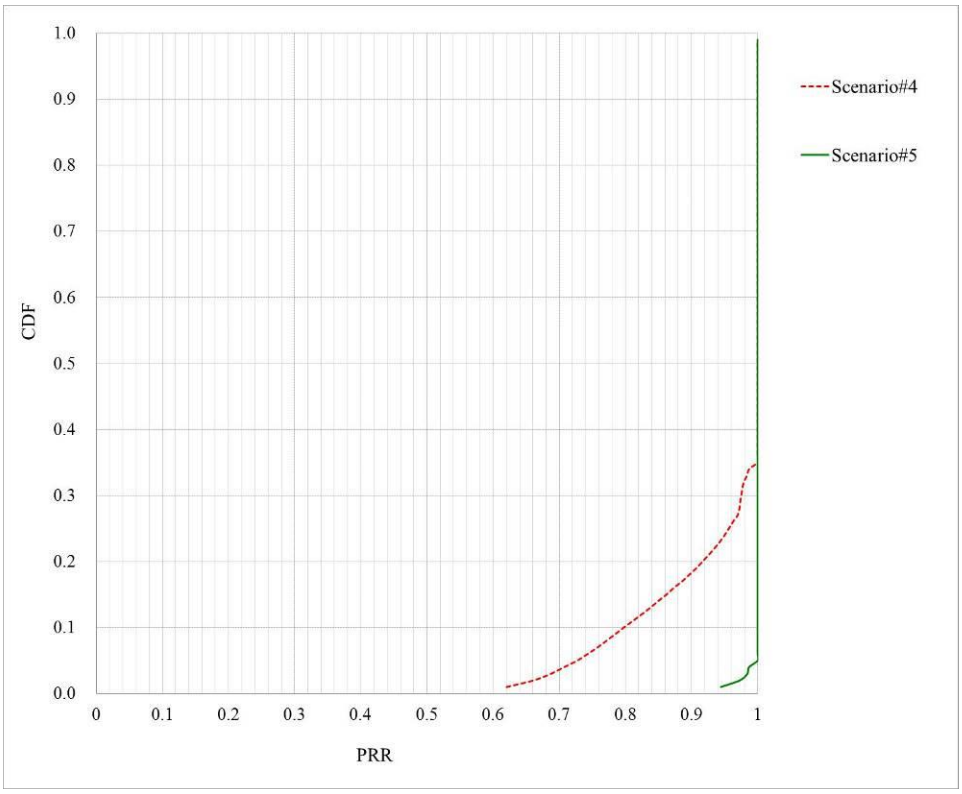
- Source 5



- Source 6


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
CDF
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
PRR
Scenario#4
Scenario#5

- Source 7


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
CDF
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
PRR
Scenario#4
Scenario#5

Annex C: Detailed evaluation results for Uu-based V2V

C.1 Simulation assumptions

Description	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6	Source 7
	Scenario#2	Scenario#3	Scenario#3	Scenario#3	Scenario#3	Scenario#3	Scenario#3
Carrier frequency (GHz)	2	2	2	2	2	2	2
Number of carriers for DL broadcast/multicast	1 (10 MHz)	1 (10 MHz)	10MHz	10MHz	10MHz	10MHz	10MHz
Amount of used resources and scheduling policy for DL broadcast/multicast	100% DL resource for DL broadcast/multicast	100% DL resource for DL broadcast/multicast	SC-PTM is used. All the 10MHz bandwidth can be used for SC-PTM transmission. The overall system resource used for V2X transmission is 54.45%	SC-PTM is used. All the 10MHz bandwidth can be used for SC-PTM transmission. The overall system resource used for V2X transmission is 62.83%	SC-PTM is used. All the 10MHz bandwidth can be used for SC-PTM transmission. The MCS of each transmission is determined by the HARQ and CQI feedback The overall system resource used for V2X transmission is 58.82%, which is 4% smaller than fixed MCS 12.The spectrum efficiency is improved by HARQ and CQI based MCS adjustment.	SC-PTM is used. All the 10MHz bandwidth can be used for SC-PTM transmission. The MCS of each transmission is determined by the HARQ and CQI feedback The overall system resource used for V2X transmission is 58.56%	SC-PTM is used. All the 10MHz bandwidth can be used for SC-PTM transmission. The MCS of each transmission is determined by the HARQ and CQI feedback The overall system resource used for V2X transmission is 57.43%, which is 5.4% smaller than fixed MCS 12. The spectrum efficiency is improved by HARQ and CQI based MCS adjustment.
MCS setting for DL broadcast/multicast	Dynamic MCS adaptation	Dynamic MCS adaptation	Fixed mcs=13	Fixed mcs=12	Use HARQ for mcs selection. The MCS adjustment scheme is first evaluated. Each packet is first transmitted using	Use HARQ for mcs selection. The MCS adjustment scheme is first evaluated. Each packet is first transmitted using	Use HARQ for mcs selection. The MCS adjustment scheme is first evaluated. Each packet is first transmitted using MCS

					MCS 13. If the portion of NACK is above a given threshold within one TTI, the next packet will be transmitted with MCS 8. The HARQ threshold is set to 0.15. If the percentage of UEs with CQI feedback smaller than a MCS (e.g., MCS 14) is lower than a given threshold, the MCS can replace MCS 13 for the first transmission. the CQI threshold is set to 0.1	MCS 13. If the portion of NACK is above a given threshold within one TTI, the next packet will be transmitted with MCS 8. The HARQ threshold is set to 0.15. If the percentage of UEs with CQI feedback smaller than a MCS (e.g., MCS 14) is lower than a given threshold, the MCS can replace MCS 13 for the first transmission. the CQI threshold is set to 0.3	13. If the portion of NACK is above a given threshold within one TTI, the next packet will be transmitted with MCS 8.The HARQ threshold is set to 0.17. If the percentage of UEs with CQI feedback smaller than a MCS (e.g., MCS 14) is lower than a given threshold, the MCS can replace MCS 13 for the first transmission. the CQI threshold is set to 0.1
Physical channel format for DL broadcast/multicast (e.g., RS, CP configuration, etc)	- DMRS-based PDSCH [18] - Normal CP	- DMRS-based PDSCH [18] - Normal CP	CRS, normal CP	CRS, normal CP	CRS, normal CP	CRS, normal CP	CRS, normal CP
Multi-cell coordination policy for DL broadcast/multicast	3 cells transmit the messages generated in the center cell of the cluster together and it takes 3 subframes to transmit whole V2X messages generated from all the associated cells [18]	7 cells transmit the messages generated in the center cell of the cluster together and it takes 7 subframes to transmit whole V2X messages generated from all the associated cells [18]	No	No	No	No	No
Remark (e.g., allowed buffering delay in eNB for DL broadcast/multicast, etc)	No buffering delay in eNB for DL broadcast/multicast is assumed in the simulation [18]	No buffering delay in eNB for DL broadcast/multicast is assumed in the simulation [18]	If the end-to-end delay exceeds 100ms, the packet will be discarded in eNB.	If the end-to-end delay exceeds 100ms, the packet will be discarded in eNB.	If the end-to-end delay exceeds 100ms, the packet will be discarded in eNB.	If the end-to-end delay exceeds 100ms, the packet will be discarded in eNB.	If the end-to-end delay exceeds 100ms, the packet will be discarded in eNB.

Description	Source 8	Source 9	Source 10	Source 11	Source 12	Source 13	Source 14
	Scenario#3	Scenario#3	Scenario#3	Scenario#2	Scenario#2	Scenario#2	Scenario#3
Carrier frequency (GHz)	2	2	2	2	2	2	2
Number of carriers for DL broadcast/multicast	10MHz	1(10MHz)	1(10MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)
Amount of used resources and scheduling policy for DL broadcast/multicast	SC-PTM is used. All the 10MHz bandwidth can be used for SC-PTM transmission. The MCS of each transmission is determined by the HARQ and CQI feedback The overall system resource used for V2X transmission is 56.45%	SC-PTM is used; 100% DL resource can be selected for SC-PTM transmission; First In First out scheduling is assumed	SC-PTM is used; 100% DL resource can be selected for SC-PTM transmission; First In First out scheduling is assumed	100%	60%	100%	100%
MCS setting for DL broadcast/multicast	Use HARQ for mcs selection. The MCS adjustment scheme is first evaluated. Each packet is first transmitted using MCS 13. If the portion of NACK is above a given threshold within one TTI, the next packet will be transmitted with MCS 8. The HARQ threshold is set to 0.17. If the percentage of UEs with CQI feedback smaller than a MCS (e.g., MCS 14) is lower than a given threshold, the MCS	Fixed, QPSK 0.33	Fixed, QPSK 0.5	12 PRBs allocation, MCS8 - packet 190 bytes, MCS12 - packet 300 bytes	Wideband allocation (50 PRBs), MCS16	Wideband allocation (50 PRBs), MCS13	10 PRBs allocation, MCS9 - packet 190 bytes, MCS14 - packet 300 bytes

	can replace MCS 13 for the first transmission. the CQI threshold is set to 0.3						
Physical channel format for DL broadcast/multicast (e.g., RS, CP configuration, etc)	CRS, normal CP	PDSCH, CRS, normal CP	PDSCH, CRS, normal CP	Normal CP, 1 CRS port, 3 symbols for control channel	Extended CP, Legacy MBSFN pilot structure, 2 symbols for control channel	Normal CP, MBSFN-like pilot structure (pilots on 3rd, 8th, 12th symbols), 2 symbols for control channel	Normal CP, 1 CRS port, 3 symbols for control channel
Multi-cell coordination policy for DL broadcast/multicast	No	No	No	Network packet forwarding using SC-PTM with non-SFN transmission in all cells (6 cells) (SCPTM-6CC)	Network packet forwarding using MBSFN with SFN transmission in all cells (6 cells) (MBSFN-SFN6)	Network packet forwarding using MBSFN with SFN transmission in all cells (6 cells) (MBSFN-SFN6)	Local packet forwarding at each Tx cell using SC-PTM and inter-cell muting with reuse-3 pattern, Proportional Time Sharing among cells (SCPTM-R3, PTS; [20])
Remark (e.g., allowed buffering delay in eNB for DL broadcast/multicast, etc)	If the end-to-end delay exceeds 100ms, the packet will be discarded in eNB.	Packet will be dropped if delay exceeds 100ms; Assuming that the geo. Information of Tx UE is known, and serving eNB can use the information to decide which cell the data should be forwarded (details in [19], note the circle radius to decide which cell should be forwarded change from 180m in [19] to 140m here)	Packet will be dropped if delay exceeds 100ms;Assuming that serving eNB of Tx UE forwards data to all its neighbour cells(details in [19])	FIFO V2V packet scheduler, Random resource selection, Data from the strongest cell is only received	FIFO V2V packet scheduler	FIFO V2V packet scheduler	FIFO V2V packet scheduler, Random resource selection, Data from the strongest cell is only received

Description	Source 15	Source 16	Source 17	Source 18	Source 19	Source 20	Source 21
	Scenario#3	Scenario#3	Scenario#3	Scenario#3	Scenario#4	Scenario#4	Scenario#4

Carrier frequency (GHz)	2	2	2	2	2	2	2
Number of carriers for DL broadcast/multicast	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)
Amount of used resources and scheduling policy for DL broadcast/multicast	60%	60%	100%	100%	100%	60%	60%
MCS setting for DL broadcast/multicast	Wideband allocation (50 PRBs), MCS13	Wideband allocation (50 PRBs), MCS10	Wideband allocation (50 PRBs), MCS12	Wideband allocation (50 PRBs), MCS6	8 PRBs allocation, MCS12 - packet 190 bytes, MCS17 - packet 300 bytes	Wideband allocation (50 PRBs), MCS16	Wideband allocation (50 PRBs), MCS15
Physical channel format for DL broadcast/multicast (e.g., RS, CP configuration, etc)	Extended CP, Legacy MBSFN pilot structure, 2 symbols for control channel	Extended CP, Legacy MBSFN pilot structure, 2 symbols for control channel	Normal CP, MBSFN-like pilot structure (pilots on 3rd, 8th, 12th symbols), 2 symbols for control channel	Normal CP, MBSFN-like pilot structure (pilots on 3rd, 8th, 12th symbols), 2 symbols for control channel	Normal CP, 1 CRS port, 3 symbols for control channel	Extended CP, Legacy MBSFN pilot structure, 2 symbols for control channel	Extended CP, Legacy MBSFN pilot structure, 2 symbols for control channel
Multi-cell coordination policy for DL broadcast/multicast	Network packet forwarding using MBSFN with SFN transmission in 7 cell cluster (MBSFN-SFN7; [20])	Network packet forwarding using MBSFN with SFN transmission in 3 cell cluster (MBSFN-SFN3; [20])	Network packet forwarding using MBSFN with SFN transmission in 7 cell cluster (MBSFN-SFN7; [20])	Network packet forwarding using MBSFN with SFN transmission in 3 cell cluster (MBSFN-SFN3; [20])	Local packet forwarding at each Tx cell using SC-PTM and inter-cell muting with reuse-3 pattern, Proportional Time Sharing among cells (SCPTM-R3, PTS; [20])	Network packet forwarding using MBSFN with SFN transmission in 7 cell cluster (MBSFN-SFN7; [20])	Network packet forwarding using MBSFN with SFN transmission in 3 cell cluster (MBSFN-SFN3; [20])
Remark (e.g., allowed buffering delay in eNB for DL broadcast/multicast, etc)	FIFO V2V packet scheduler	FIFO V2V packet scheduler	FIFO V2V packet scheduler	FIFO V2V packet scheduler	FIFO V2V packet scheduler, Random resource selection, Data from the strongest cell is only received	FIFO V2V packet scheduler	FIFO V2V packet scheduler

Description	Source 22	Source 23	Source 24	Source 25	Source 26	Source 27	Source 28

	Scenario#4	Scenario#4	Scenario#3	Scenario#3	Scenario#3	Scenario#3	Scenario#3
Carrier frequency (GHz)	2	2	2	2	2	2	2
Number of carriers for DL broadcast/multicast	1 (10 MHz)	1 (10 MHz)	10Mhz	10Mhz	10Mhz	10Mhz	10Mhz
Amount of used resources and scheduling policy for DL broadcast/multicast	100%	100%	MBMS. All 10Mhz bandwidth is used for MBMS. 60% subframes constraint is applied. The TB size is determined by the used MCS, then we pack as much packet as possible into this TB	MBMS. All 10Mhz bandwidth is used for MBMS. 60% subframes constraint is applied. The TB size is determined by the used MCS, then we pack as much packet as possible into this TB	MBMS. All 10Mhz bandwidth is used for MBMS. 60% subframes constraint is applied. The TB size is determined by the used MCS, then we pack as much packet as possible into this TB	MBMS. All 10Mhz bandwidth is used for MBMS. 60% subframes constraint is applied. The TB size is determined by the used MCS, then we pack as much packet as possible into this TB	MBMS. All 10Mhz bandwidth is used for MBMS. 60% subframes constraint is applied. The TB size is determined by the used MCS, then we pack as much packet as possible into this TB
MCS setting for DL broadcast/multicast	Wideband allocation (50 PRBs), MCS16	Wideband allocation (50 PRBs), MCS15	QPSK, code rate 0.5 MCS is chosen to maximise performance	QPSK code rate 0.66 MCS is chosen to maximise performance	16QAM, code rate 0.5 MCS is chosen to maximise performance	QPSK code rate 0.66 MCS is chosen to maximise performance	16QAM, code rate 0.5 MCS is chosen to maximise performance
Physical channel format for DL broadcast/multicast (e.g., RS, CP configuration, etc)	Normal CP, MBSFN-like pilot structure (pilots on 3rd, 8th, 12th symbols), 2 symbols for control channel	Normal CP, MBSFN-like pilot structure (pilots on 3rd, 8th, 12th symbols), 2 symbols for control channel	CRS, normal CP	CRS, extended CP	CRS, extended CP	CRS, normal CP	CRS, normal CP
Multi-cell coordination policy for DL broadcast/multicast	Network packet forwarding using MBSFN with SFN transmission in 7 cell cluster (MBSFN-SFN7; [20])	Network packet forwarding using MBSFN with SFN transmission in 3 cell cluster (MBSFN-SFN3; [20])	Reuse-3: each cell transmits once every 3 subframes. No retransmitting. UE can receive message from un-associated eNBs.	3 cells location based MBMS group.	7 cells location based MBMS group.	3 cells location based MBMS group.	7 cells location based MBMS group.

Remark (e.g., allowed buffering delay in eNB for DL broadcast/multicast, etc)	FIFO V2V packet scheduler	FIFO V2V packet scheduler	If the end-to-end delay exceeds 100ms, the packet will be discarded in eNB.	If the end-to-end delay exceeds 100ms, the packet will be discarded in eNB.	If the end-to-end delay exceeds 100ms, the packet will be discarded in eNB.	If the end-to-end delay exceeds 100ms, the packet will be discarded in eNB.	If the end-to-end delay exceeds 100ms, the packet will be discarded in eNB.

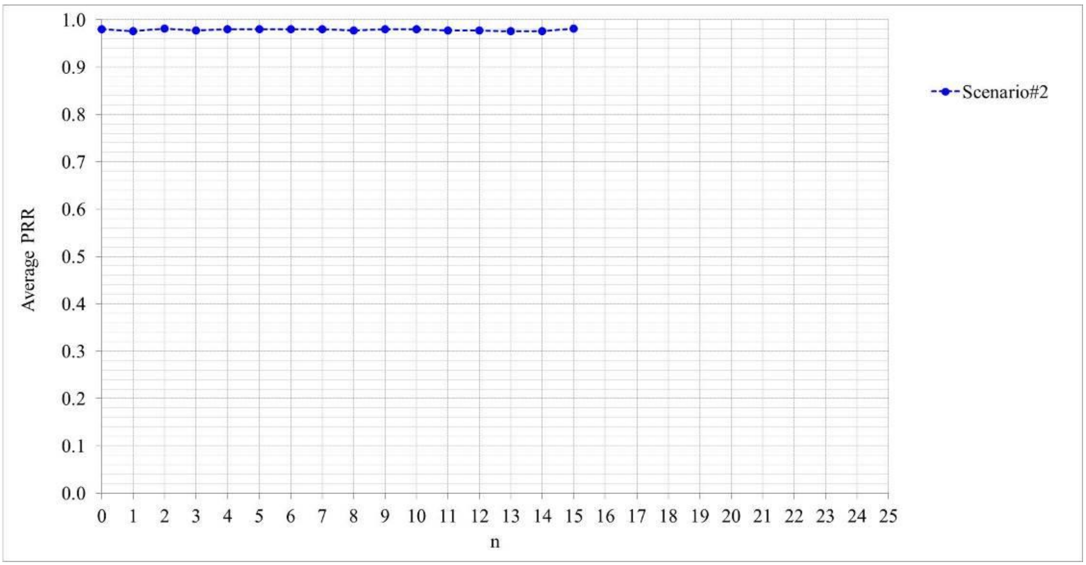
Description	Source 29	Source 30	Source 31	Source 32	Source 33
	Scenario#4	**Scenario#4**	**Scenario#4**	**Scenario#4**	**Scenario#4**
Carrier frequency (GHz)	2	2	2	2	2
Number of carriers for DL broadcast/multicast	10Mhz	10Mhz	10Mhz	10Mhz	10Mhz
Amount of used resources and scheduling policy for DL broadcast/multicast	MBMS. All 10Mhz bandwidth is used for MBMS. 60% subframes constraint is applied. The TB size is determined by the used MCS, then we pack as much packet as possible into this TB	MBMS. All 10Mhz bandwidth is used for MBMS. 60% subframes constraint is applied. The TB size is determined by the used MCS, then we pack as much packet as possible into this TB	MBMS. All 10Mhz bandwidth is used for MBMS. 60% subframes constraint is applied. The TB size is determined by the used MCS, then we pack as much packet as possible into this TB	MBMS. All 10Mhz bandwidth is used for MBMS. 60% subframes constraint is applied. The TB size is determined by the used MCS, then we pack as much packet as possible into this TB	MBMS. All 10Mhz bandwidth is used for MBMS. 60% subframes constraint is applied. The TB size is determined by the used MCS, then we pack as much packet as possible into this TB
MCS setting for DL broadcast/multicast	16QAM, code rate 0.5 MCS is chosen to maximise performance	16QAM, code rate 0.5 MCS is chosen to maximise performance	16QAM, code rate 0.66 MCS is chosen to maximise performance	16QAM, code rate 0.5 MCS is chosen to maximise performance	16QAM, code rate 0.66 MCS is chosen to maximise performance
Physical channel format for DL broadcast/multicast (e.g., RS, CP configuration, etc)	CRS, normal CP	CRS, extended CP	CRS, extended CP	CRS, normal CP	CRS, normal CP
Multi-cell coordination policy for DL broadcast/multicast	Reuse-3: each cell transmits once every 3 subframes. No retransmitting. UE can receive message	3 cells location based MBMS group.	7 cells location based MBMS group.	3 cells location based MBMS group.	7 cells location based MBMS group.

	from un-associated eNBs.				
Remark (e.g., allowed buffering delay in eNB for DL broadcast/multicast, etc)	If the end-to-end delay exceeds 100ms, the packet will be discarded in eNB.	If the end-to-end delay exceeds 100ms, the packet will be discarded in eNB.	If the end-to-end delay exceeds 100ms, the packet will be discarded in eNB.	If the end-to-end delay exceeds 100ms, the packet will be discarded in eNB.	If the end-to-end delay exceeds 100ms, the packet will be discarded in eNB.

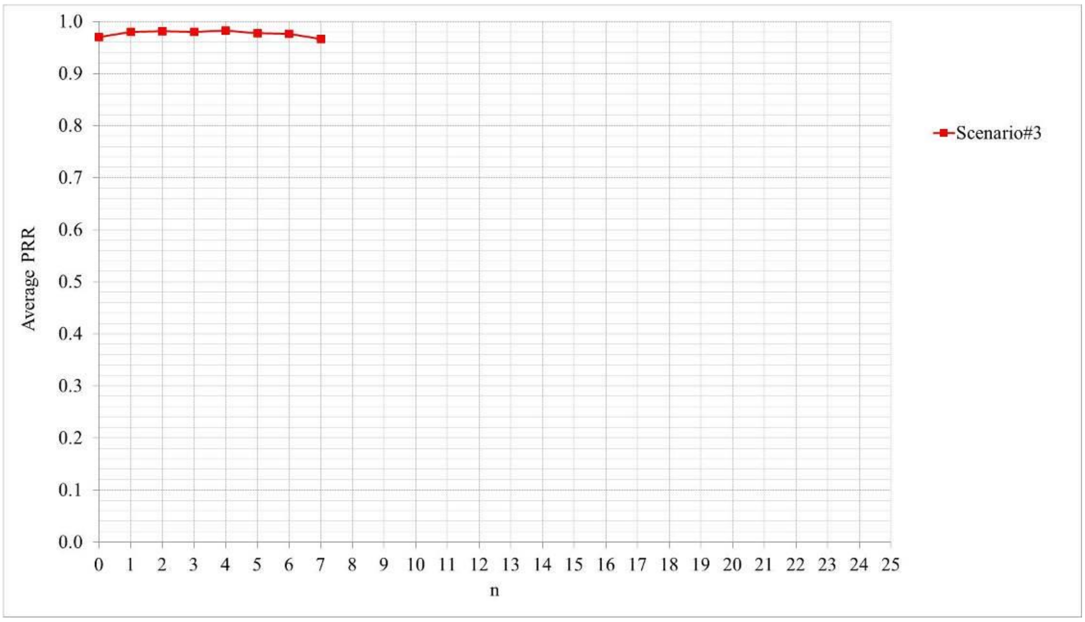
C.2 Simulation results

Average PRR of each source is as follows (a=n*20 m, b=(n+1)*20 m):

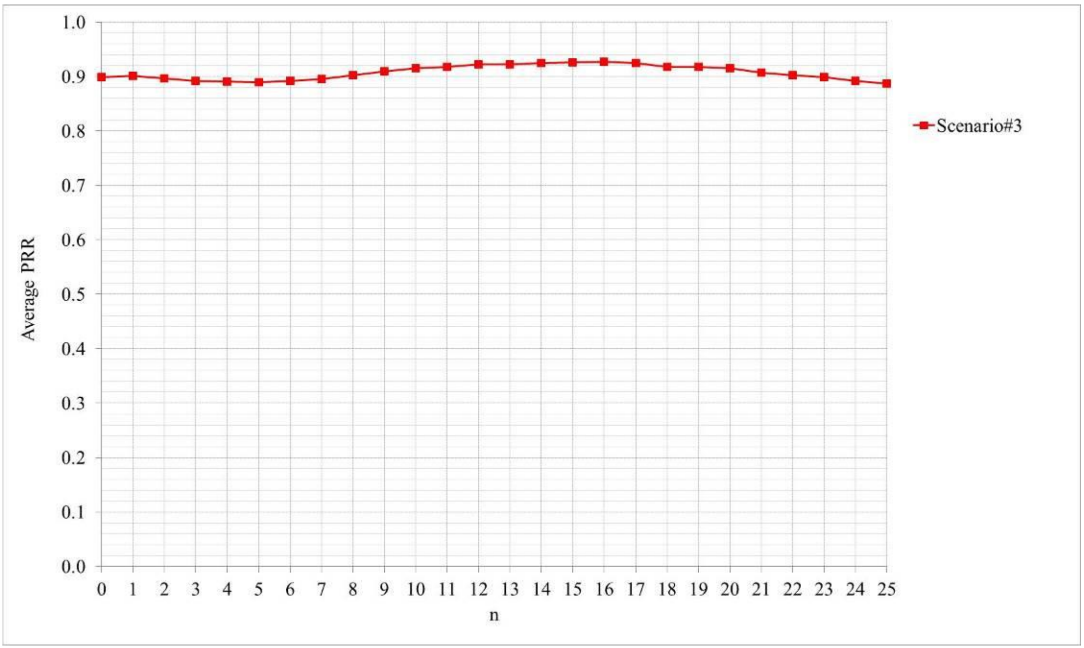
- Source 1



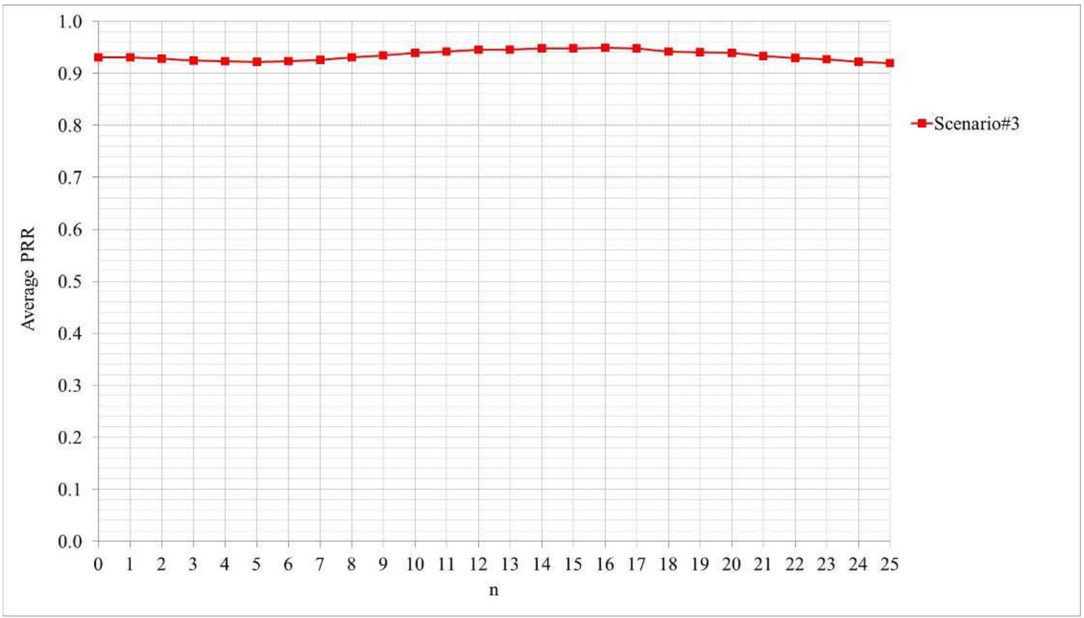
- Source 2



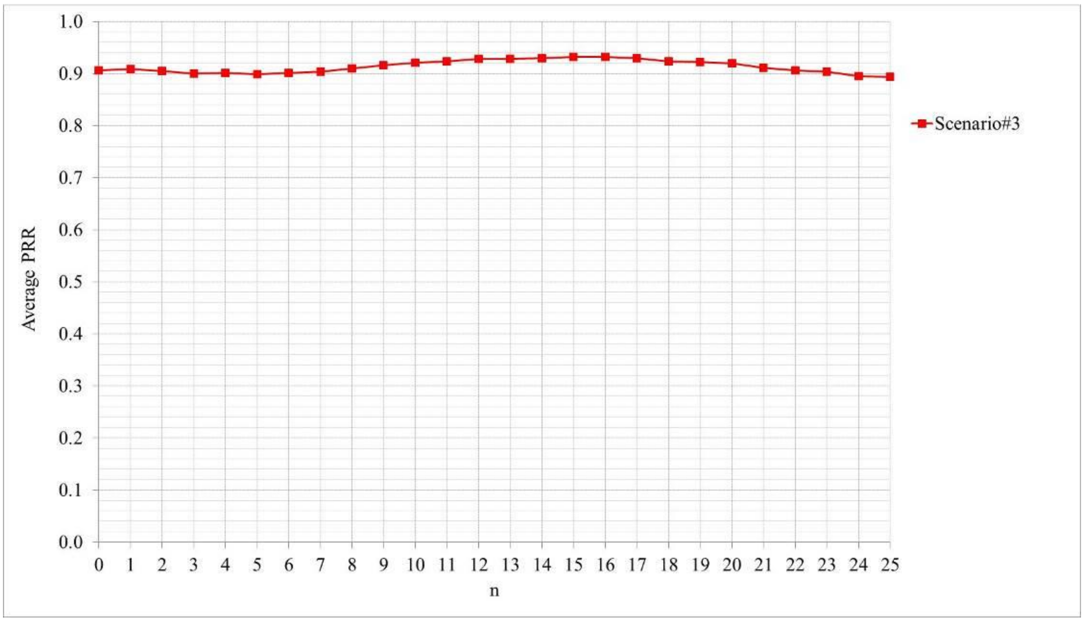
- Source 3



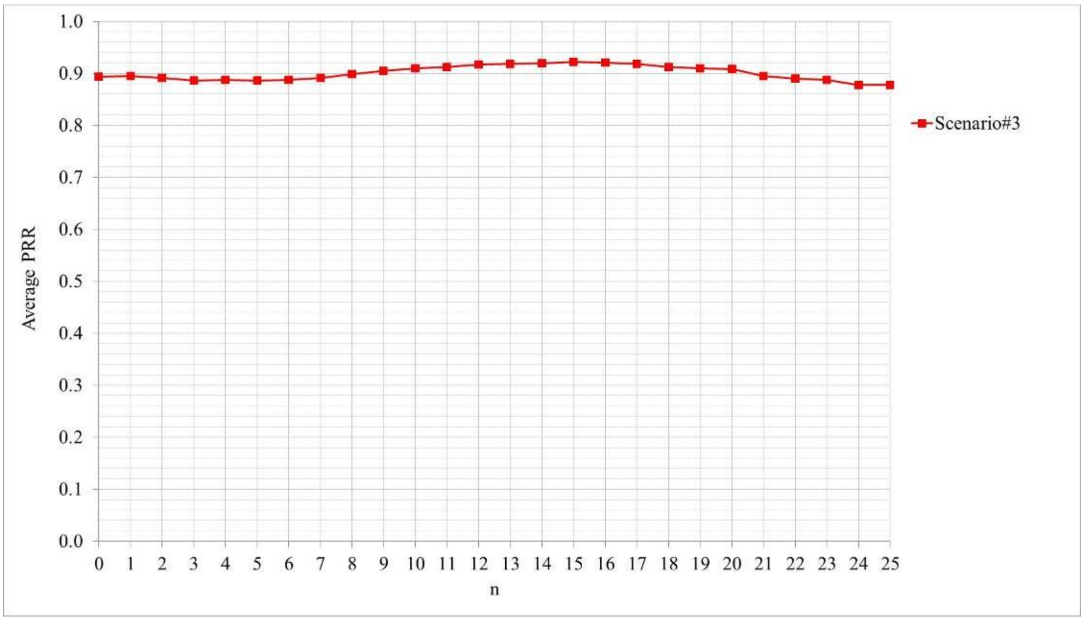
- Source 4



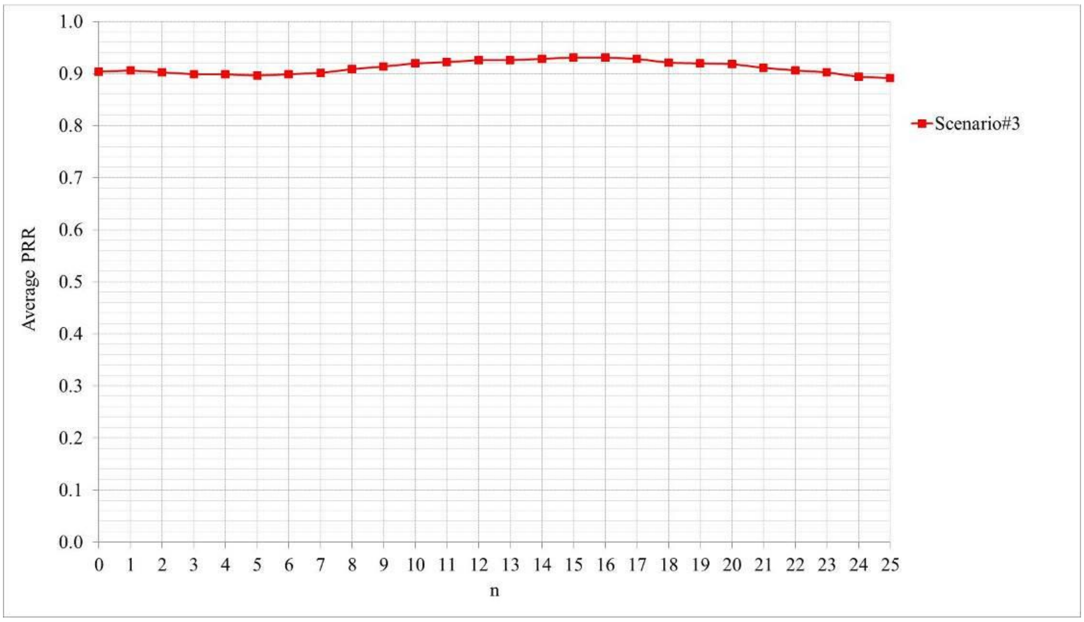
- Source 5



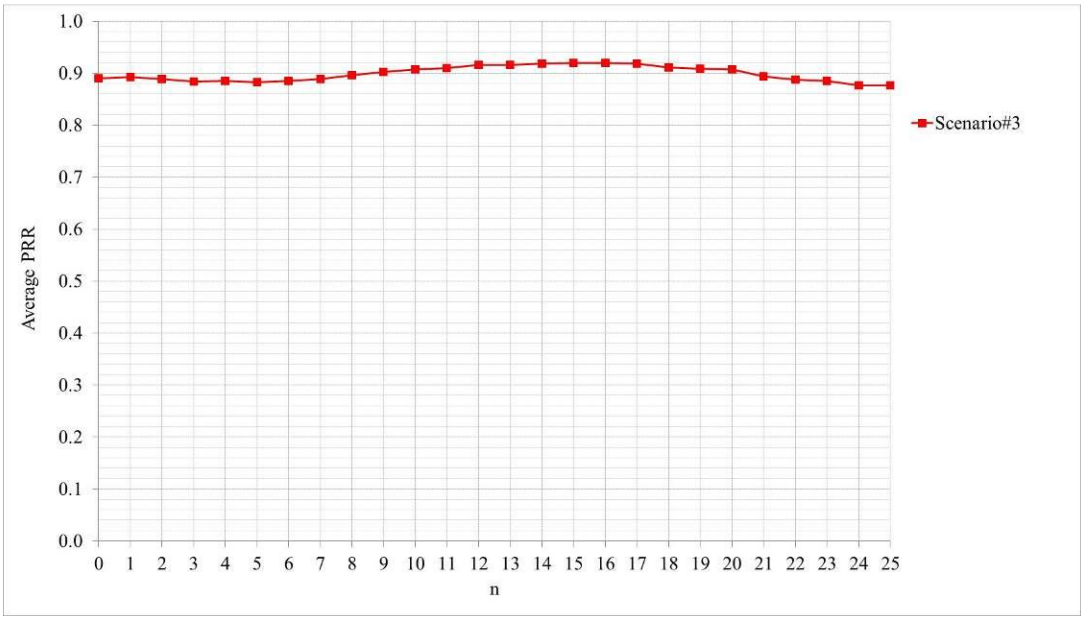
- Source 6



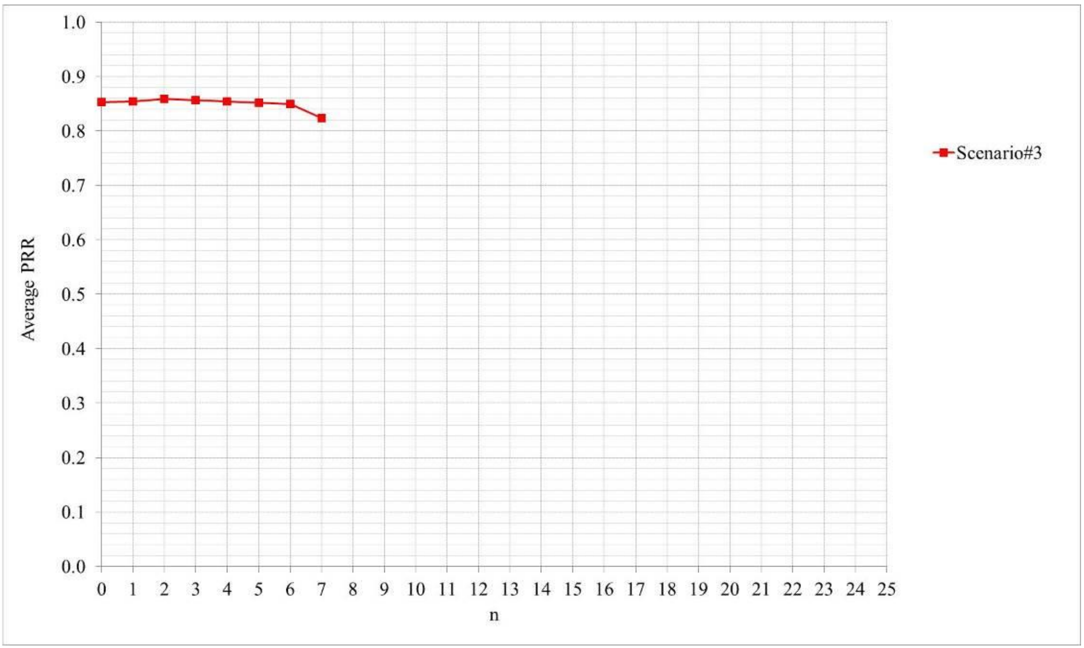
- Source 7



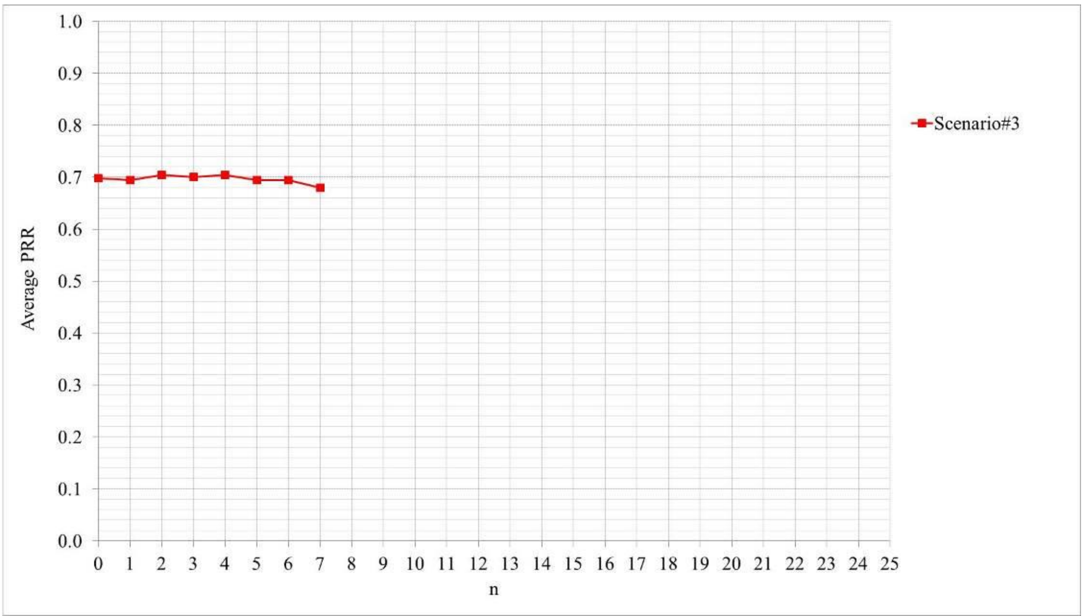
- Source 8



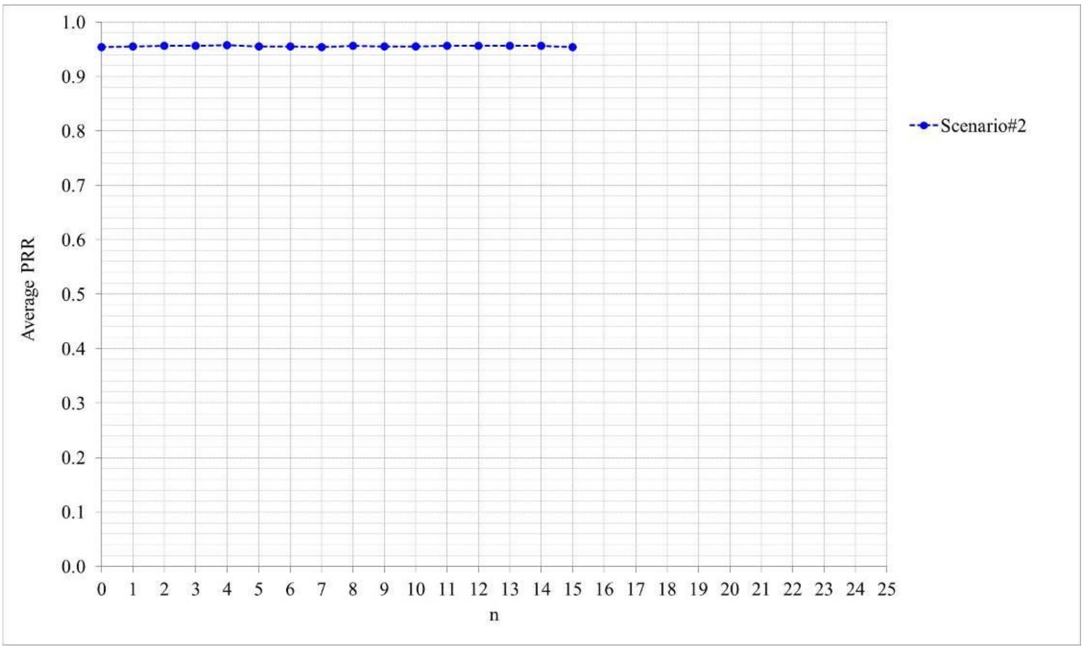
- Source 9



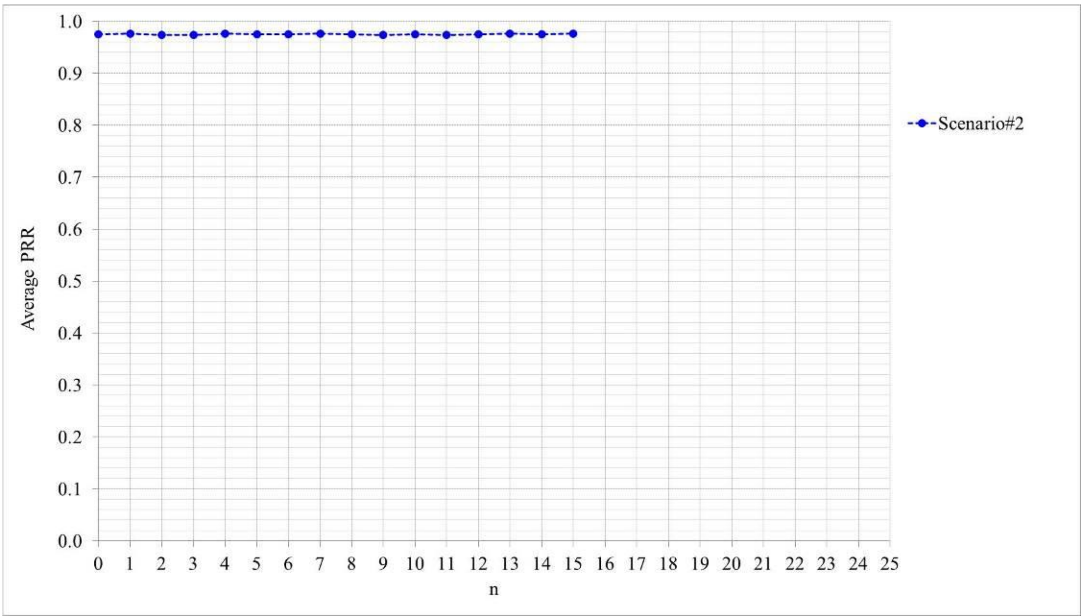
- Source 10



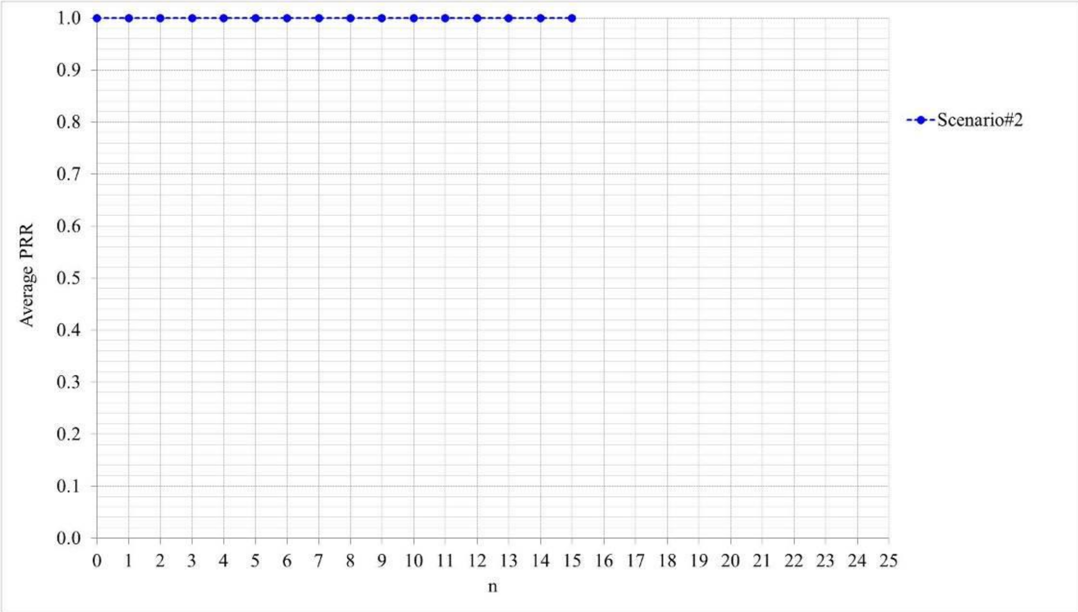
- Source 11



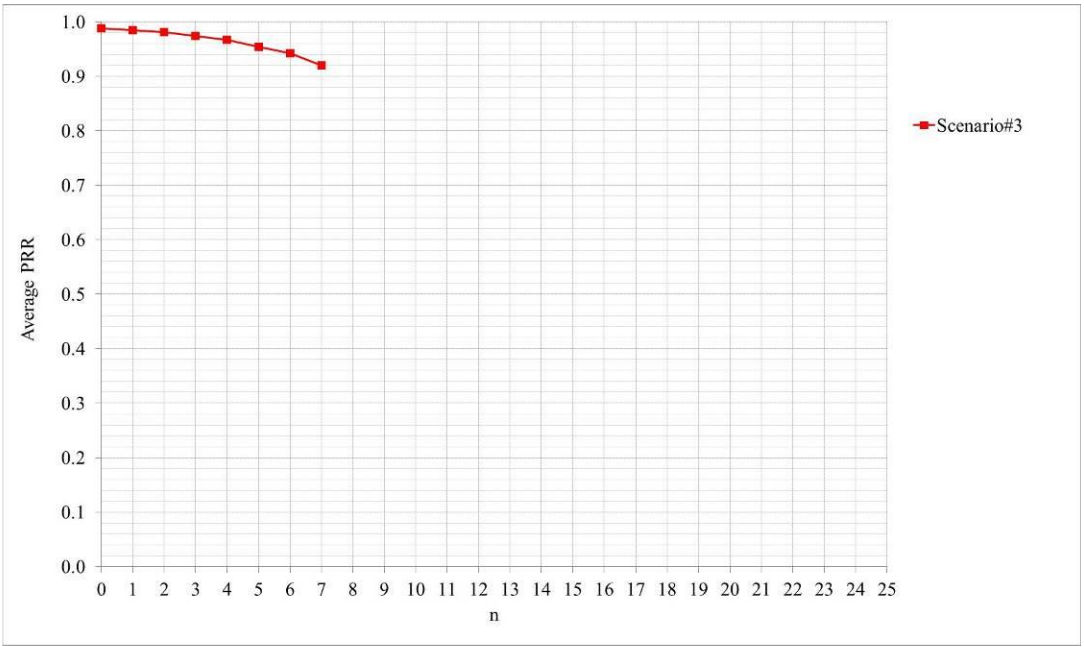
- Source 12



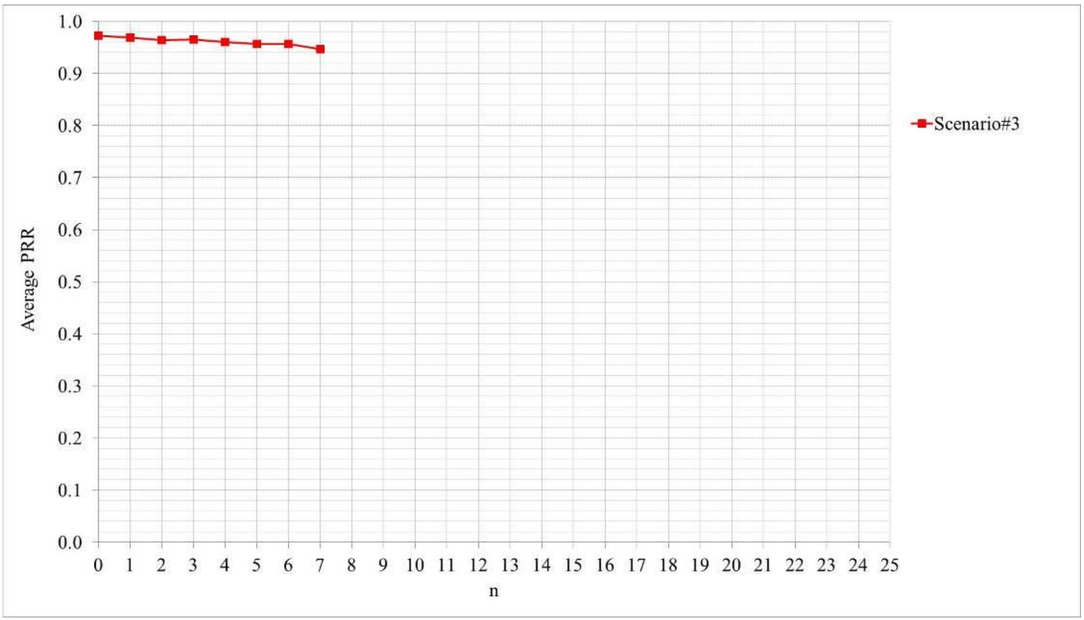
- Source 13



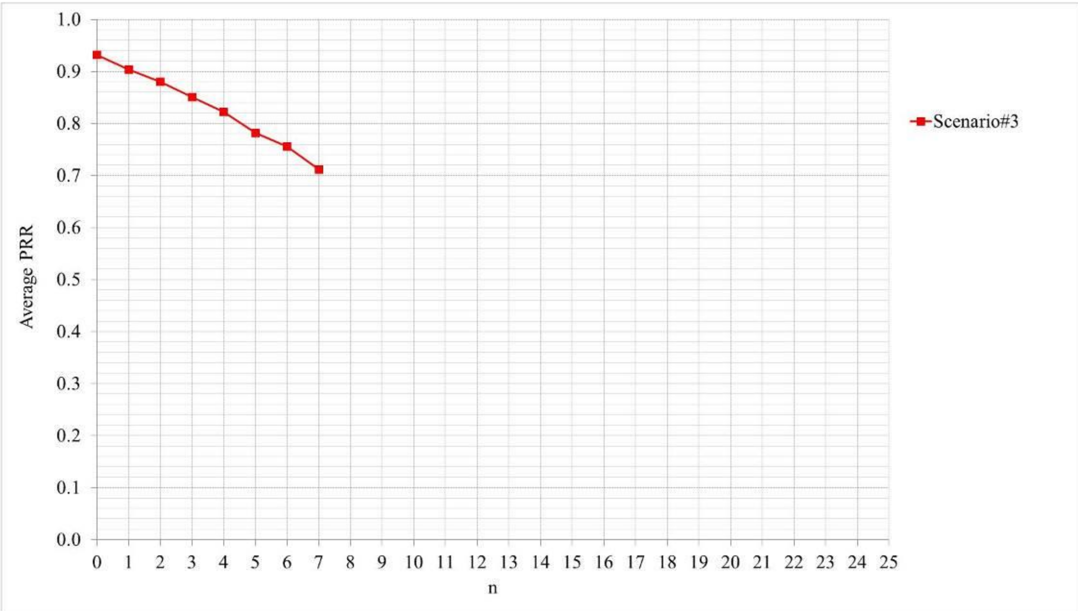
- Source 14



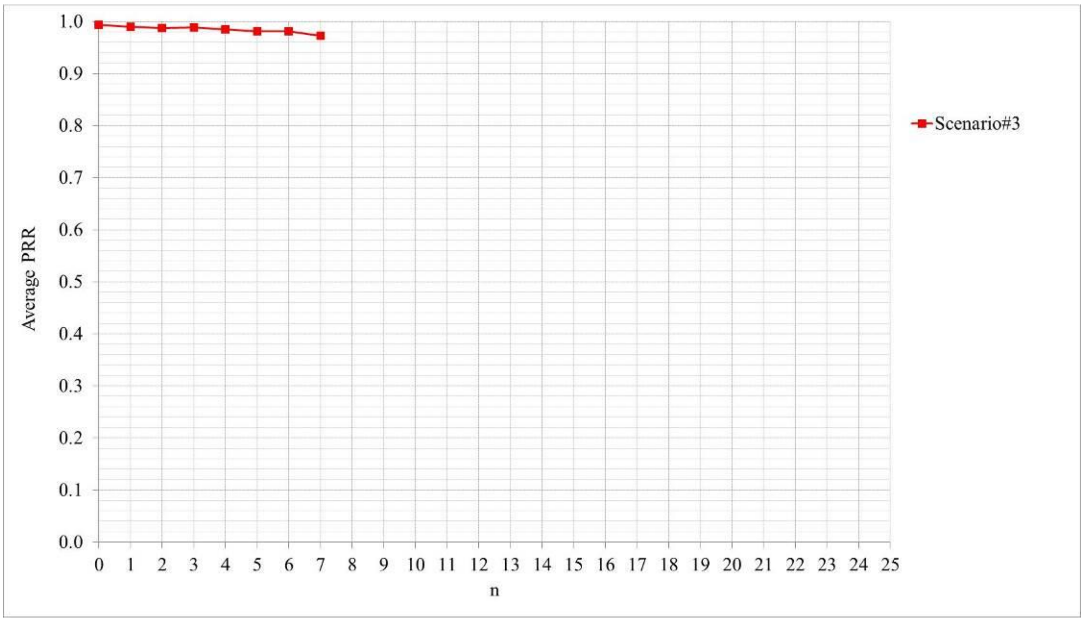
- Source 15



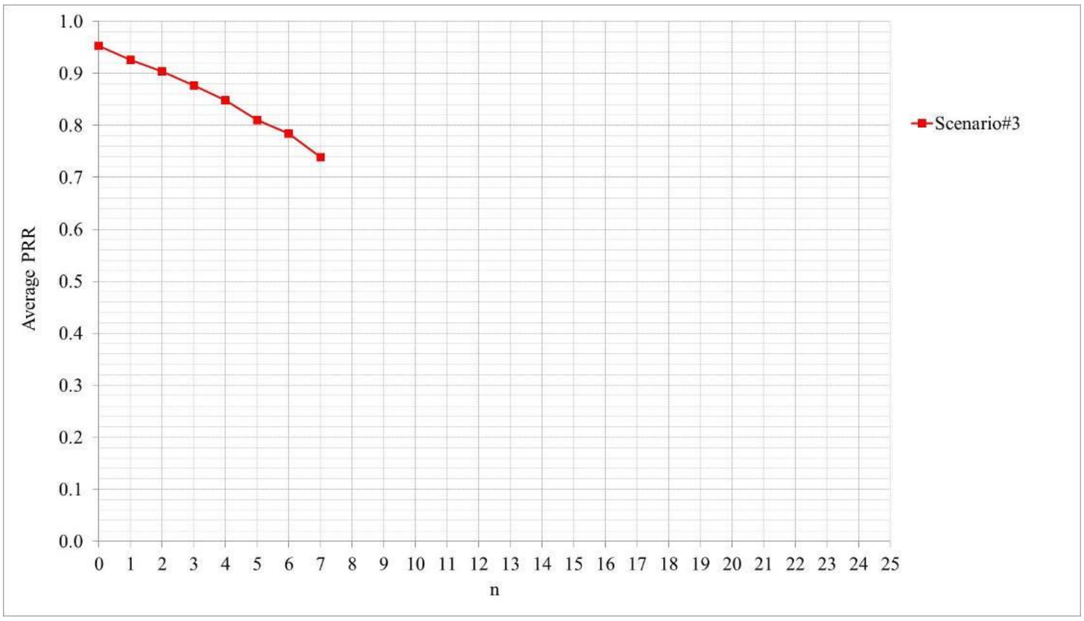
- Source 16



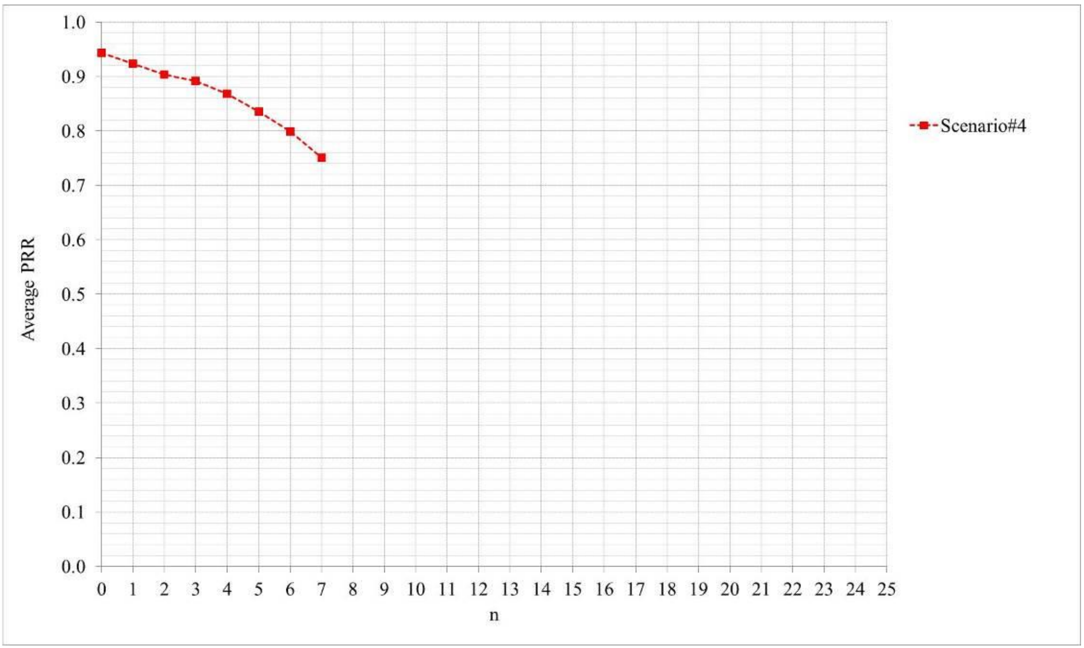
- Source 17



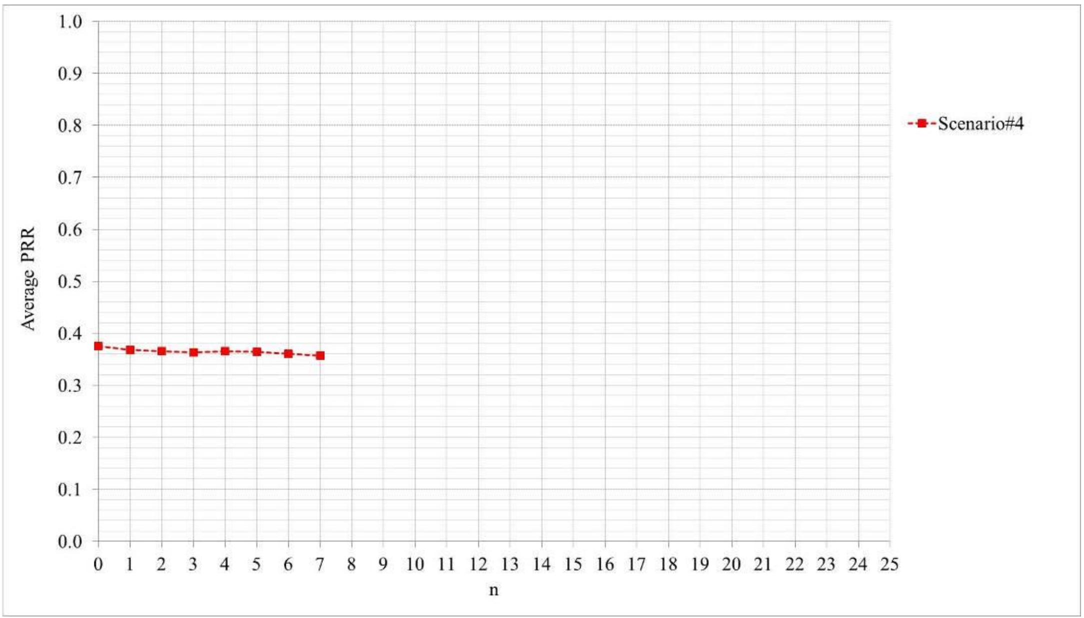
- Source 18



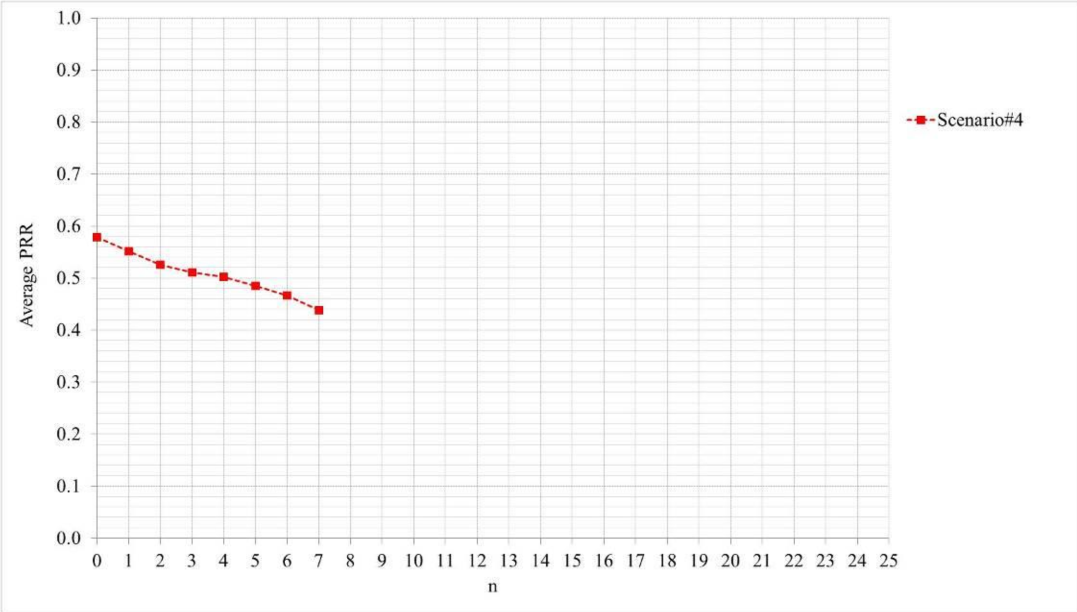
- Source 19



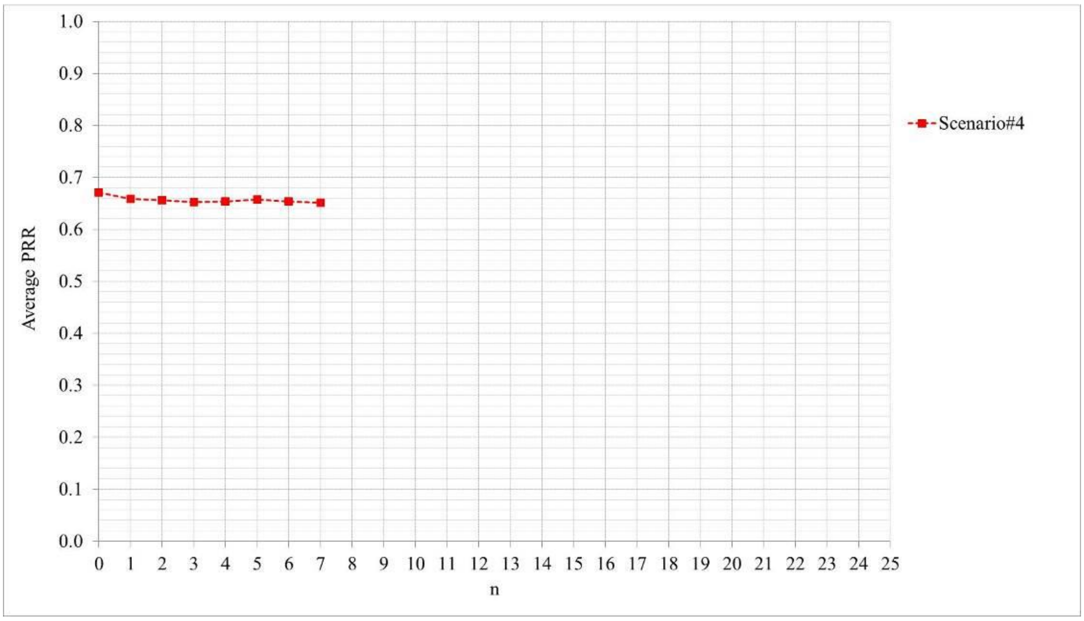
- Source 20



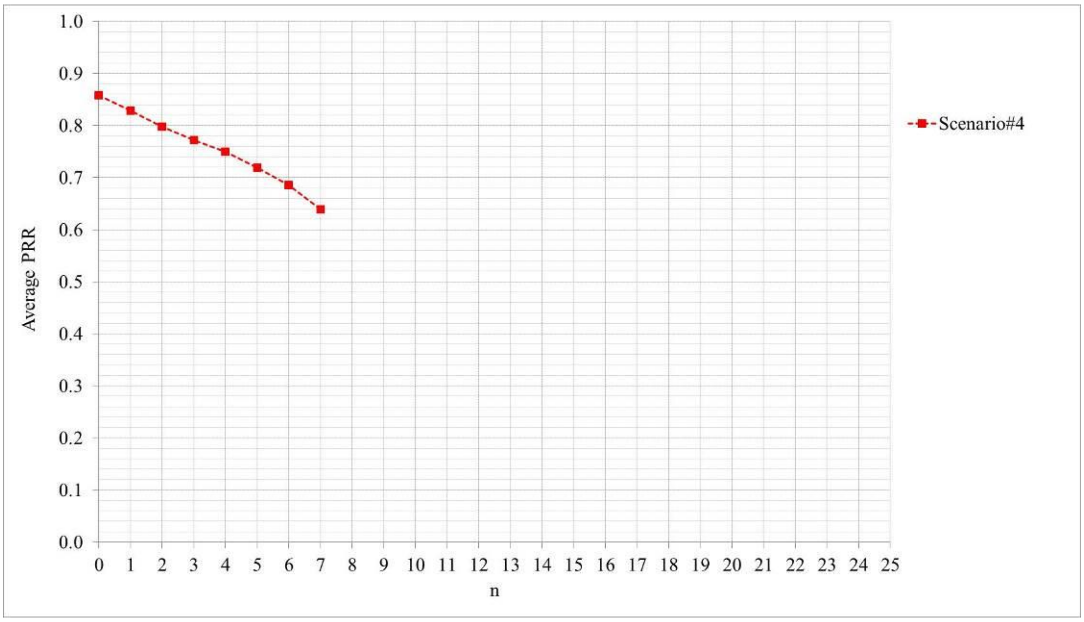
- Source 21



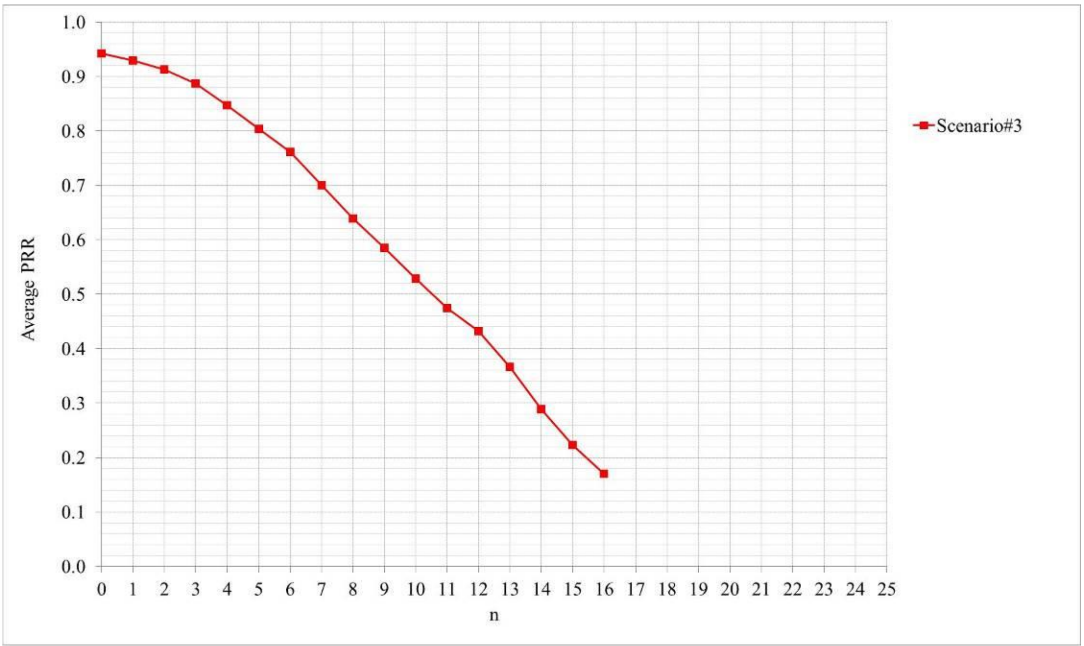
- Source 22



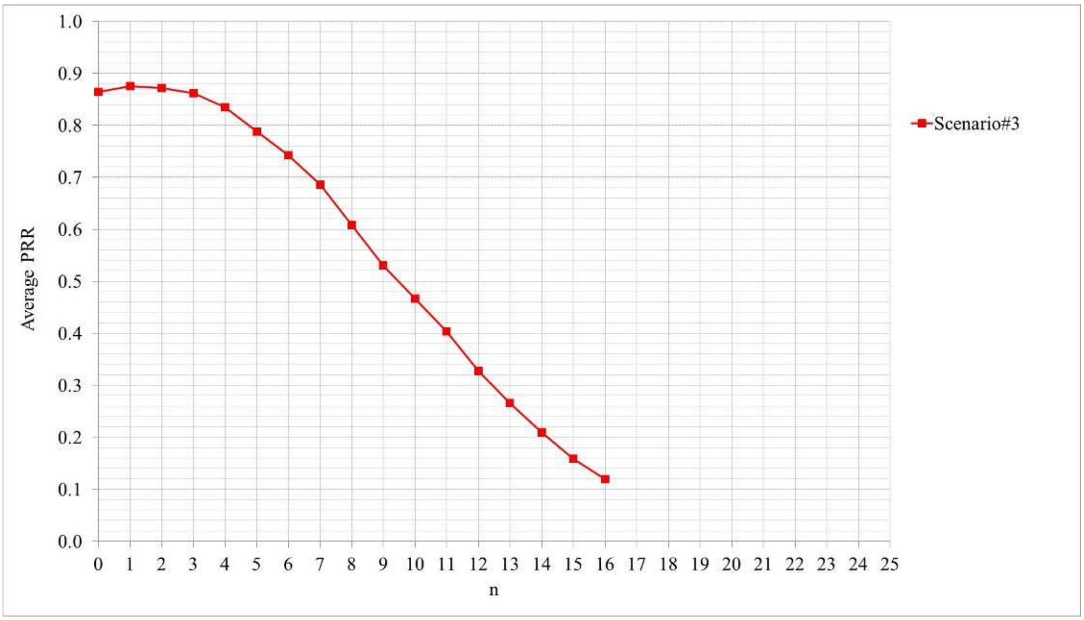
- Source 23



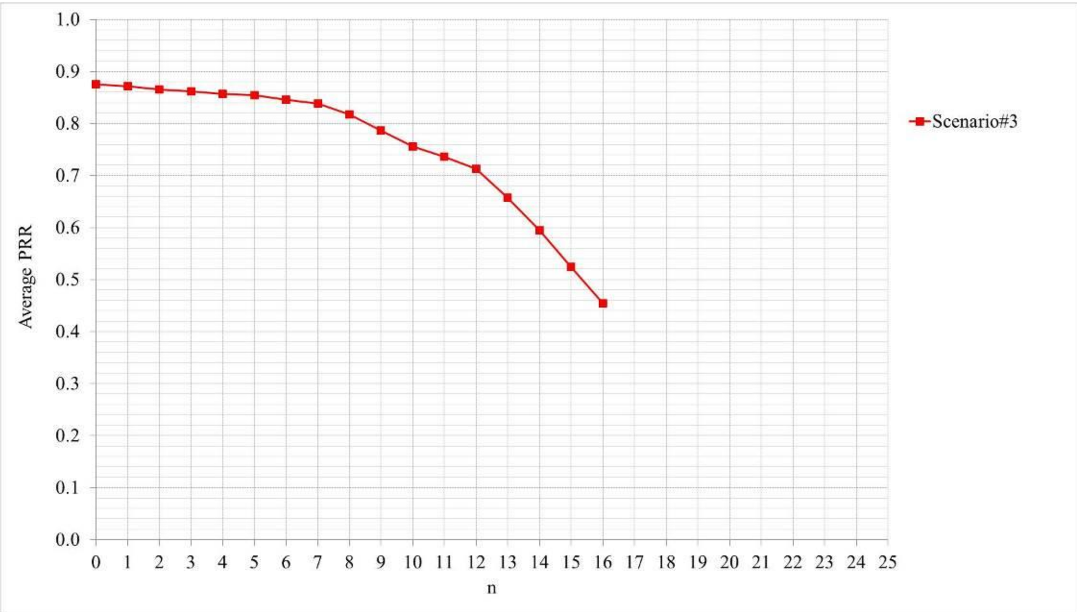
- Source 24



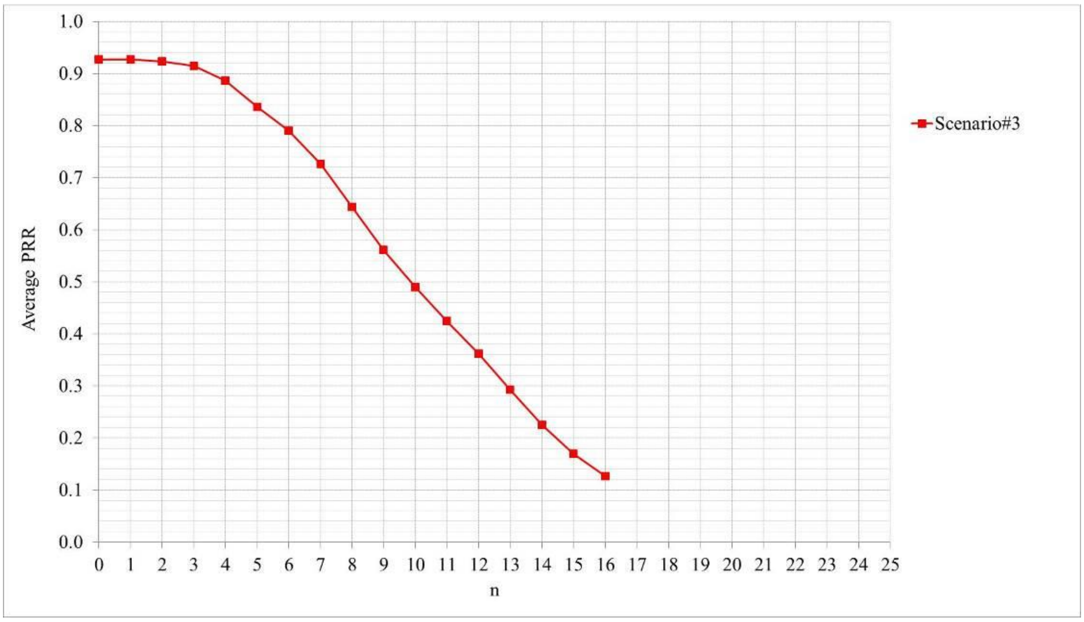
- Source 25



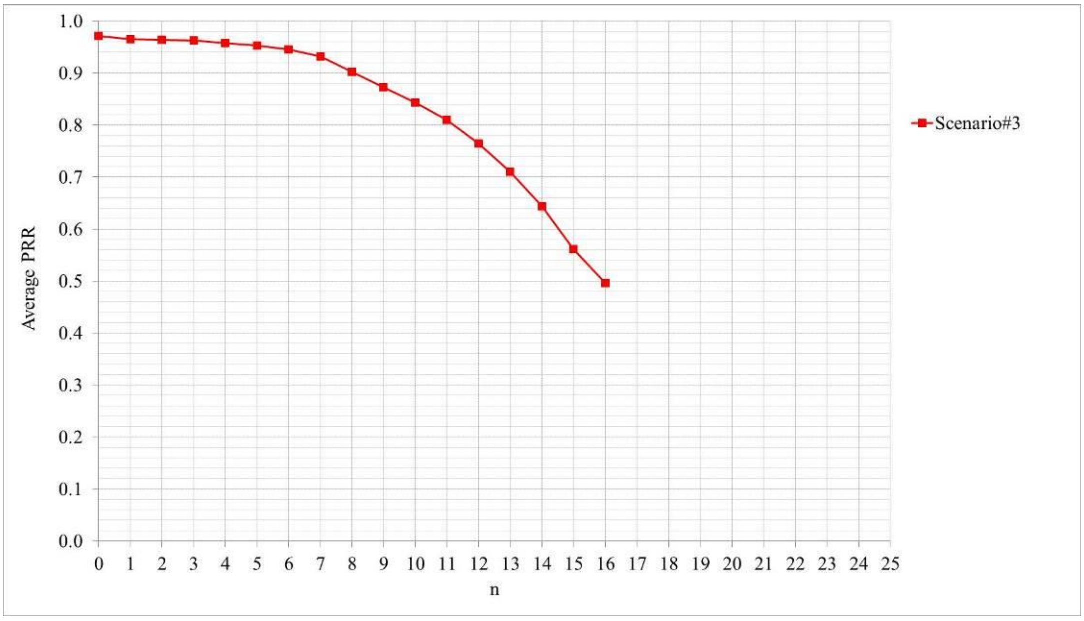
- Source 26



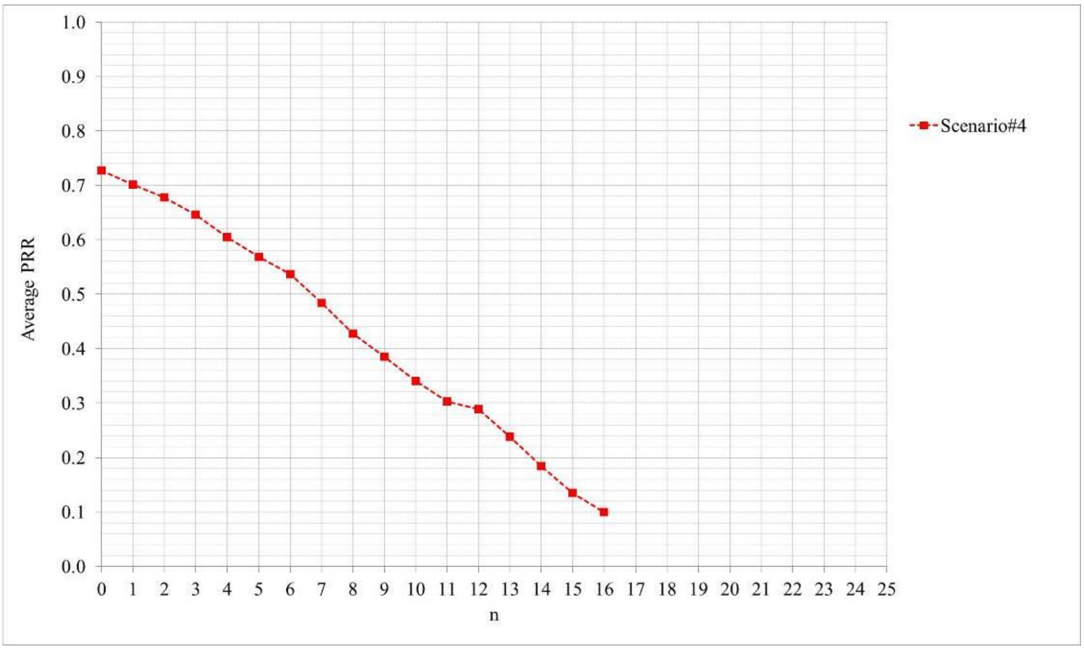
- Source 27



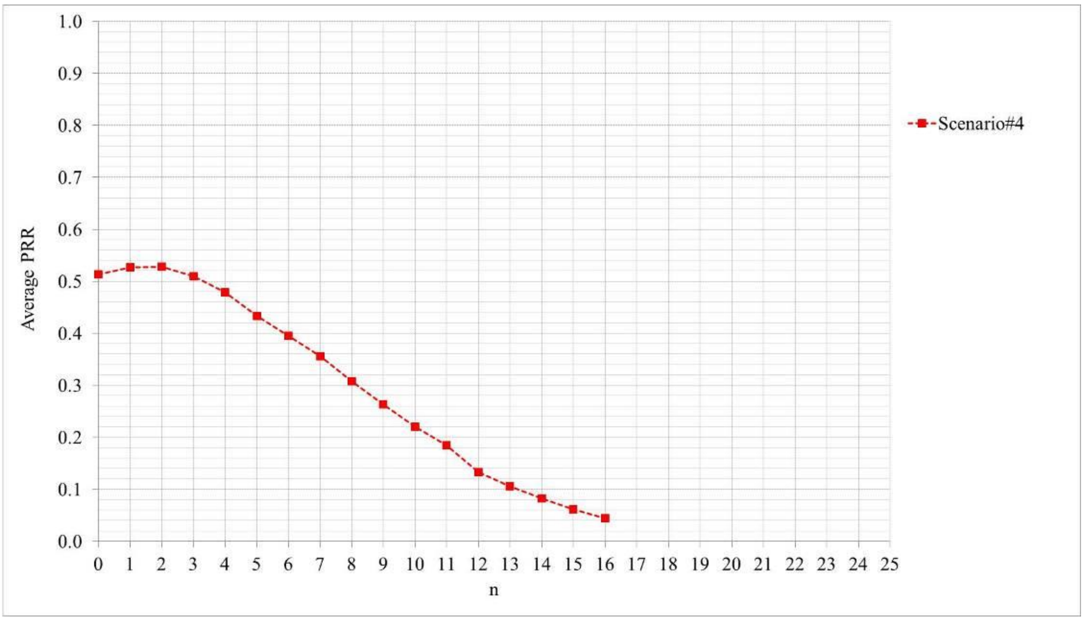
- Source 28



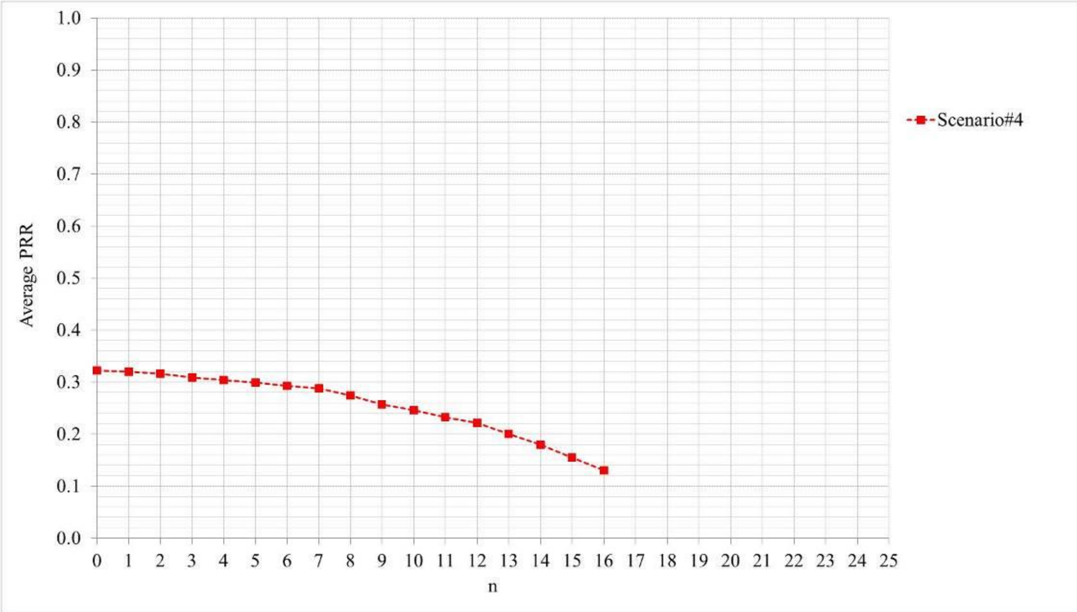
- Source 29



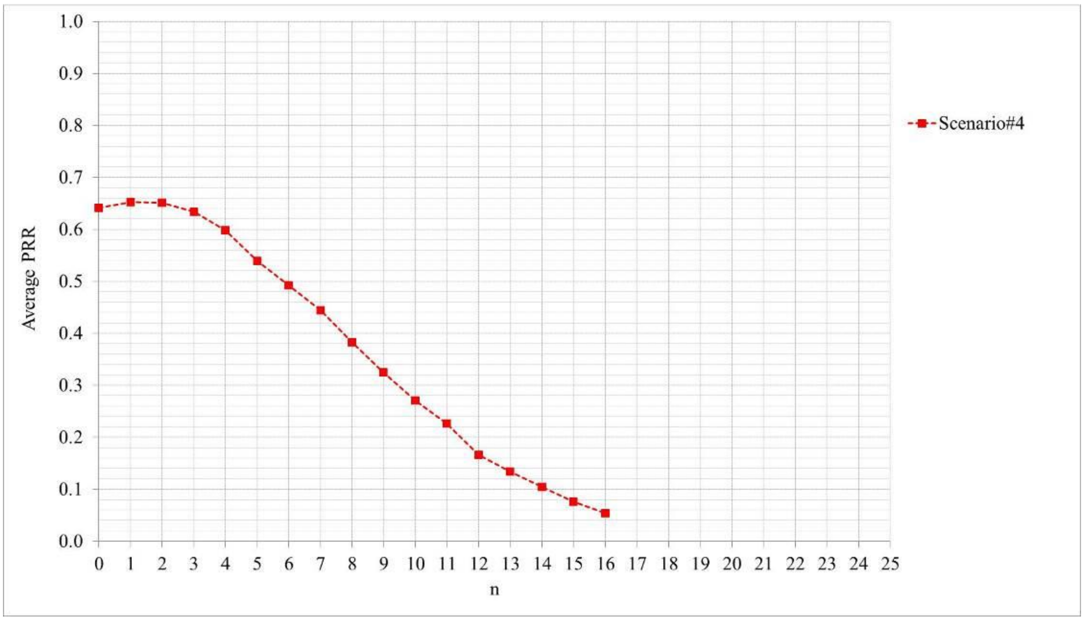
- Source 30



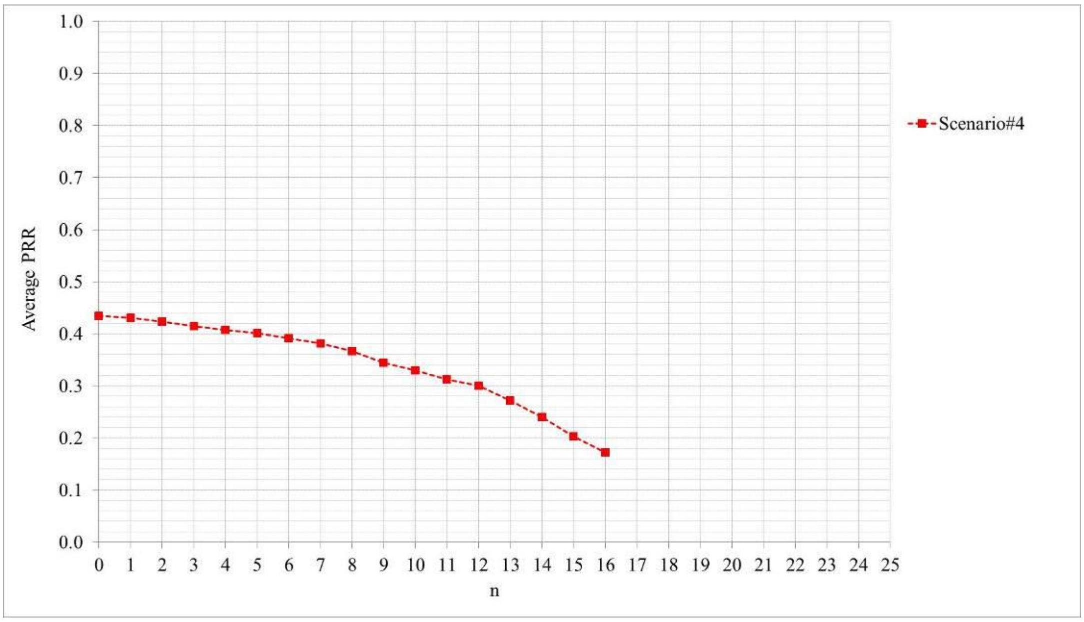
- Source 31



- Source 32



- Source 33


Average PRR
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
n
Scenario#4

Annex D: Detailed evaluation results for Uu-based V2I/N

D.1 Simulation assumptions

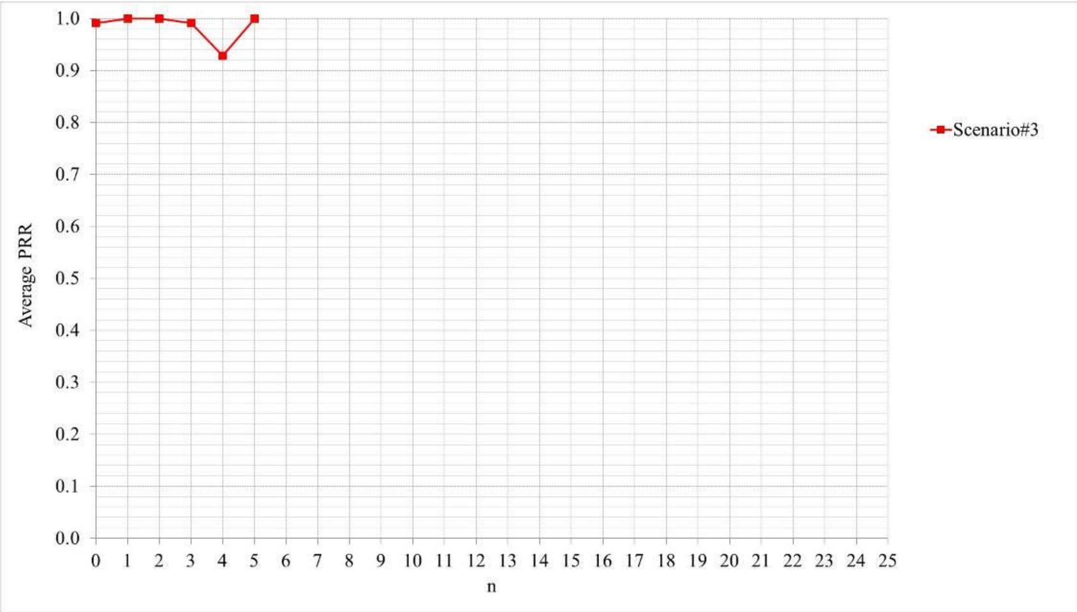
Description	Source 1	Source 2	Source 3	Source 4	Source 5
	Scenario#3	**Scenario#3**	**Scenario#4**	**Scenario#3**	**Scenario#4**
Carrier frequency (GHz)	2	2	2	2	2
Number of carriers for DL broadcast/multicast	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)
I2V Traffic model (e.g., model 1, 2)	I2V traffic model 1 is assumed in the simulation [21]	Model 1 (Details [22])	Model 1 (Details [22])	Model 1	Model 1
Amount of used resources and scheduling policy for DL broadcast/multicast	100% DL resource for DL broadcast/multicast	100% DL resource can be selected	100% DL resource can be selected	100% DL resource can be selected	100% DL resource can be selected
MCS setting for DL broadcast/multicast	Select minimum MCS among all the MCS values which can support V2X message size needed to be transmitted (under the fixed scheduled RB size)	QPSK 0.22	QPSK 0.22	QPSK 0.4385	QPSK 0.4385
Physical channel format for DL broadcast/multicast (e.g., RS, CP configuration, etc)	- PMCH [21] - Extended CP	SC-PTM, PDSCH CRS, normal CP	SC-PTM, PDSCH CRS, normal CP	SC-PTM, PDSCH CRS, normal CP	SC-PTM, PDSCH CRS, normal CP

Multi-cell coordination policy for DL broadcast/multicast	3 eNB-type RSUs transmit the messages generated in the intersection together and it takes 2 subframes to transmit whole V2X messages generated from all intersections [21]	No	No	Network packet forwarding using SC-PTM with non-SFN transmission in all cells (3 cells) (SCPTM-3CC)	Network packet forwarding using SC-PTM with non-SFN transmission in all cells (3 cells) (SCPTM-3CC)
Remark (e.g., allowed buffering delay in eNB for DL broadcast/multicast, communication range if traffic model2 is used for Uu I2V, etc)	No buffering delay in eNB-type RSU for DL broadcast/multicast is assumed in the simulation [21]	Data will be dropped if delay exceeds 100ms [22]	Data will be dropped if delay exceeds 100ms [22]	Data will be dropped if delay exceeds 100ms	Data will be dropped if delay exceeds 100ms

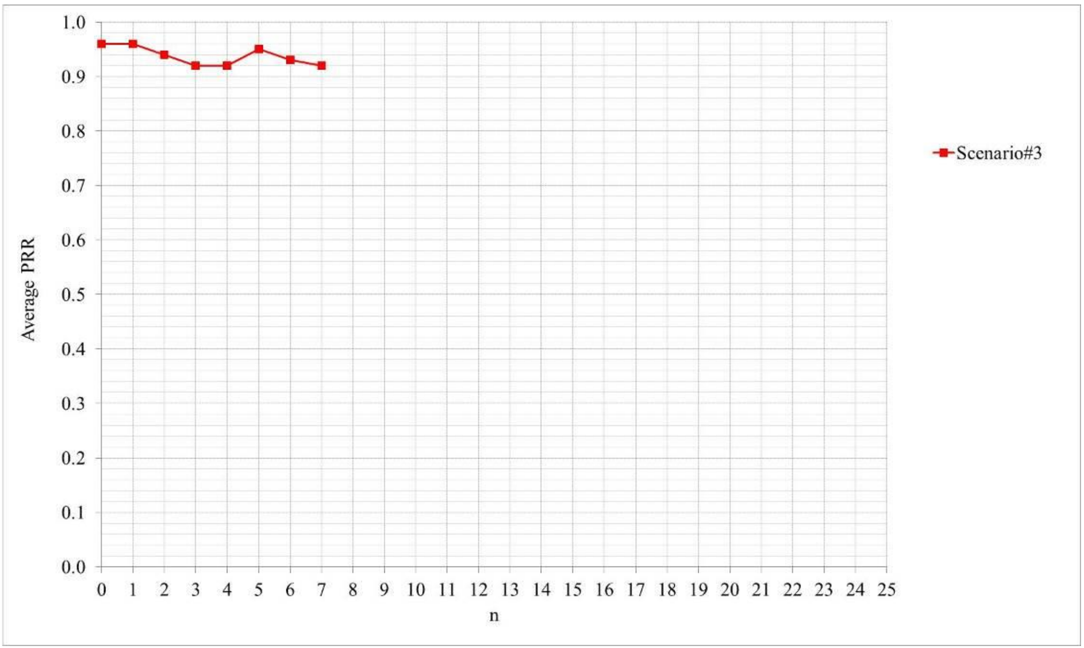
D.2 Simulation results

Average PRR of each source is as follows (a=n*20 m, b=(n+1)*20 m):

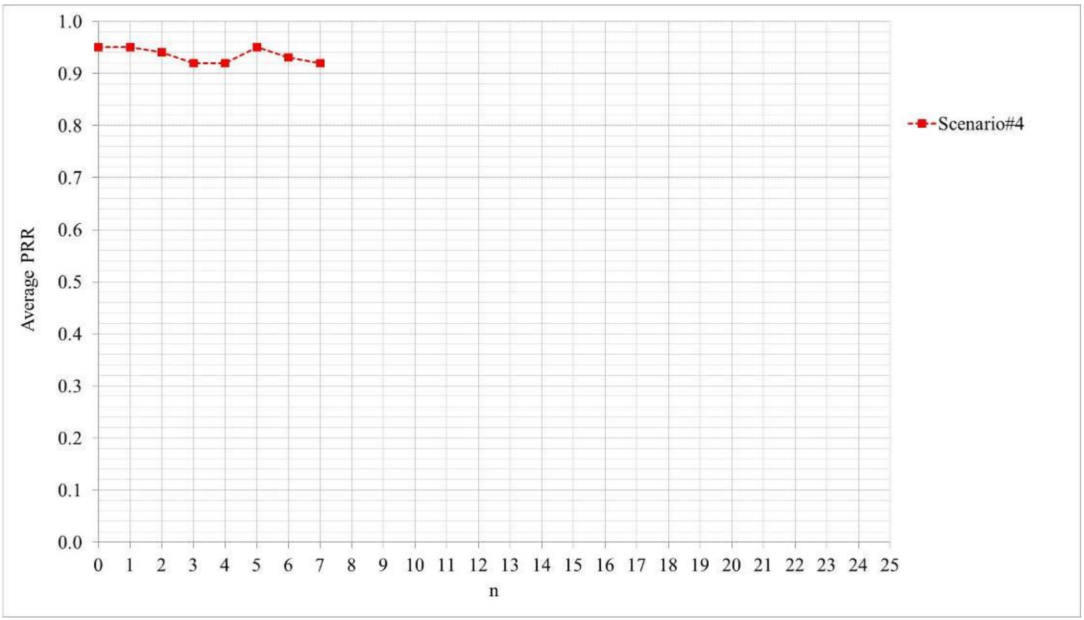
- Source 1



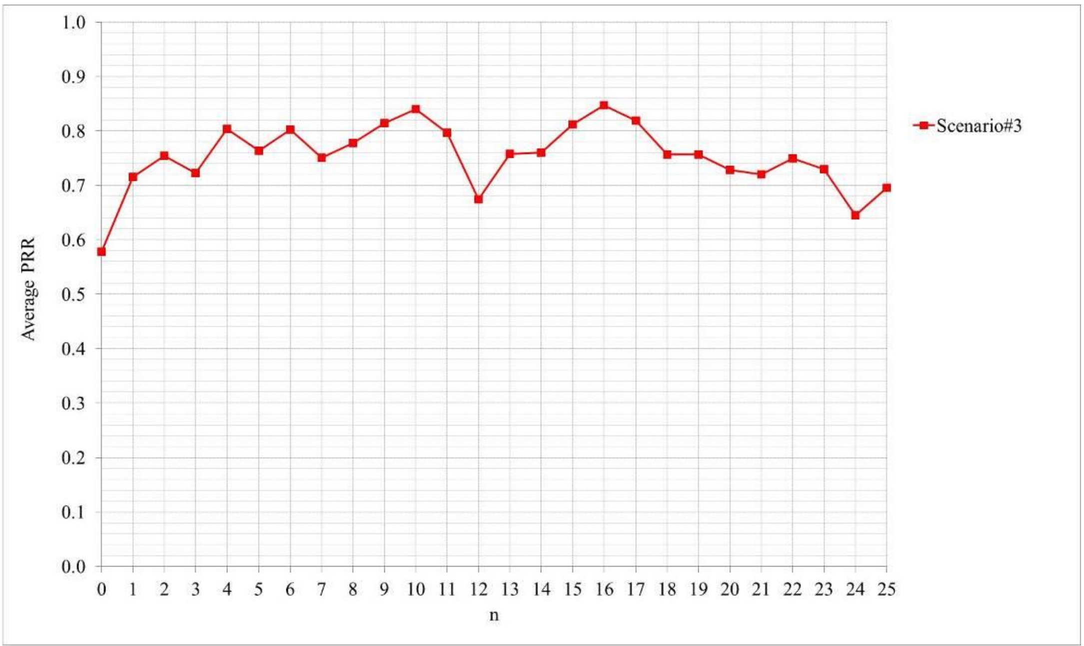
- Source 2



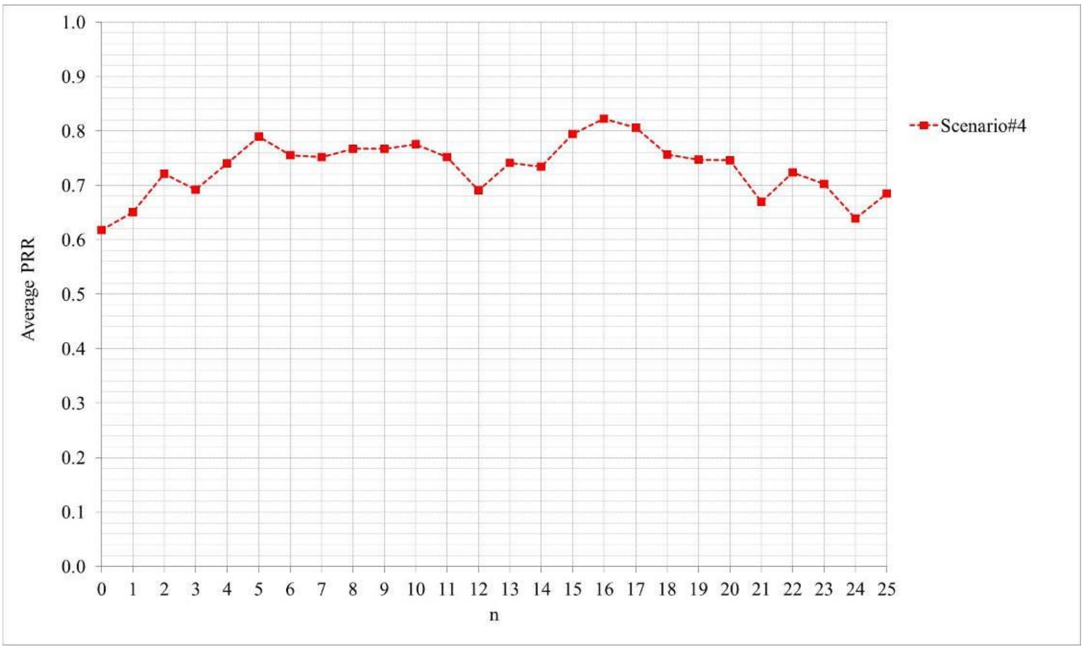
- Source 3



- Source 4



- Source 5


Average PRR
n
Scenario#4
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

Annex E: Detailed evaluation results for PC5-based V2I/N

E.1 Simulation assumptions

Description		Source 1	Source 2	Source 3	Source 4	Source 5	Source 6	Source 7
		Scenario#3	Scenario#4	Scenario#2	Scenario#3	Scenario#3	Scenario#3	Scenario#4
Carrier frequency (GHz)		6	6	6	6	6	6	6
Number of carriers		1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10MHz)	1 (10MHz)	1 (10MHz)
I2V Traffic model (e.g., model 1, 2)		Model 1	Model 1	Model 1	Model 1	Model 1	Model 1	Model 1
Number of subframes used to transmit each message	**190 bytes**	4 (4 control + data)	4 (4 control + data)	2	2	1	1	1 (1 control + 1 data)
	300 bytes	4 (4 control + data)	4 (4 control + data)	4	4	1	1	1 (1 control + 1 data)
Number of RBs used to transmit each message in each subframe	**190 bytes**	12 RBs	12 RBs	10	10	14 PRBs	14 PRBs	14 PRBs
	300 bytes	16 RBs	16 RBs	10	10	14 PRBs	14 PRBs	14 PRBs
Modulation	**190 bytes**	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK
	300 bytes	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK

Transmission power (in case of non-zero MPR, actual power after applying MPR)	23 dBm	23 dBm	21dBm	21dBm	23dBm	23dBm	23dBm
Physical channel format (e.g., RS)	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol comb-type DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol comb-type DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol comb DMRS at #2, #5, #8, #11 for both control and data	4 symbol comb DMRS at #2, #5, #8, #11 for both control and data	4 symbol comb DMRS at #2, #5, #8, #11 for both control and data
MPR and inband emission model	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	2 dB，{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	2 dB ，{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843
Synchronization assumptions	Ideal time and frequency synchronization.	Ideal time and frequency synchronization.	Ideal time synchronization.	Ideal time synchronization.	Ideal time and frequency synchronization.	Ideal time and frequency synchronization.	Ideal time and frequency synchronization.
SA assumption (e.g., SA overhead)	The SA and the associated data are transmitted in the same subframe and one SA occupies one PRB.	The SA and the associated data are transmitted in the same subframe and one SA occupies one PRB.	Control channel containing 70-bit SA is transmitted in 2 PRB pair in a subframe of the corresponding data transmissions	Control channel containing 70-bit SA is transmitted in 2 PRB pair in a subframe of the corresponding data transmissions	The SA and associated data are transmitted in the same subframe; SA and data pool are FDMed, 8 PRB for SA and 42 PRB for data in Freq. domain	The SA and associated data are transmitted in the same subframe; SA and data pool are FDMed, 8 PRB for SA and 42 PRB for data in Freq. domain	The SA and associated data are transmitted in the same subframe; SA and data pool are FDMed, 8 PRB for SA and 42 PRB for data in Freq. domain
Resource allocation principle	Random	Random	"Enhanced sensing based semi-persistent resource occupy": - UE sensing available resource via SA decoding and energy measurement. - Each SA indicates the data transmission resource in current TTI, and upcoming N transmission(s) resource, where the indicated N	"Enhanced sensing based semi-persistent resource occupy": - UE sensing available resource via SA decoding and energy measurement. - Each SA indicates the data transmission resource in current TTI, and upcoming N transmission(s) resource, where the indicated N transmissions resource can be used	Sensing based resource selection - energy sensing, and the resource with least receiving energy is selected; Assuming UE enters NW one by one.	Sensing based resource selection - energy sensing, and the resource with least receiving energy is selected; Assuming UE enters NW one by one.	Sensing based resource selection - energy sensing, and the resource with least receiving energy is selected; Assuming UE enters NW one by one.

			transmissions resource can be used a different TB. - Reselection duration prefer 1 transmission period (100ms). - See more detail in [23].	a different TB. - Reselection duration prefer 1 transmission period (100ms). - See more detail in [23].			
Remark (e.g., communication range if traffic model2 is used for PC5 I2V, etc)					Orthogonal resource pool (I2V and V2V TDMed, 7 subframes for I2V and 43 subframes for V2V every 50ms)	Shared resource pool	Orthogonal resource pool (I2V and V2V TDMed, 7 subframes for I2V and 43 subframes for V2V every 50ms)

Description		**Source 8**	**Source 9**	**Source 10**	**Source 11**	**Source 12**	**Source 13**	**Source 14**
		Scenario#4	**Scenario#2**	**Scenario#2**	**Scenario#3**	**Scenario#3**	**Scenario#2**	**Scenario#3**
Carrier frequency (GHz)		6	6	6	6	6	6	6
Number of carriers		1 (10MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)
I2V Traffic model (e.g., model 1, 2)		Model 1	Model 1	Model 2	Model 1	Model 2	Model 1	Model 1
Number of subframes used to transmit each message	**190 bytes**	1 (1 control + 1 data)	2 (2 control + 2 data)	2 (2 control + 2 data)	2 (2 control + 2 data)	2 (2 control + 2 data)	1	1
	300 bytes	1 (1 control + 1 data)	2 (2 control + 2 data)	2 (2 control + 2 data)	2 (2 control + 2 data)	2 (2 control + 2 data)	1	1
Number of RBs used to transmit each message	**190 bytes**	14 PRBs	10 RBs	10 RBs	10 RBs	10 RBs	16RBs	16RBs

in each subframe	**300 bytes**	14 PRBs	15 RBs	15 RBs	15 RBs	15 RBs	25RBs	25RBs
Modulation	**190 bytes**	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK
	300 bytes	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK
Transmission power (in case of non-zero MPR, actual power after applying MPR)		23dBm	23 dBm	23 dBm	23 dBm	23 dBm	23dBm	23dBm
Physical channel format (e.g., RS)		4 symbol comb DMRS at #2, #5, #8, #11 for both control and data	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data
MPR and inband emission model		'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843
Synchronization assumptions		Ideal time and frequency synchronization.	Ideal time and frequency synchronization.	Ideal time and frequency synchronization.	Ideal time and frequency synchronization.	Ideal time and frequency synchronization.	Ideal time synchronization and frequency offset	Ideal time synchronization and frequency offset
SA assumption (e.g., SA overhead)		The SA and associated data are transmitted in the same subframe; SA and data pool are FDMed, 8 PRB for SA and 42 PRB for data in Freq. domain	The SA and the associated data are transmitted in the same subframe and one SA occupies one PRB.	The SA and the associated data are transmitted in the same subframe and one SA occupies one PRB.	The SA and the associated data are transmitted in the same subframe and one SA occupies one PRB.	The SA and the associated data are transmitted in the same subframe and one SA occupies one PRB.	The SA and the associated data are transmitted in the same subframe.SA and data pool are FDMed, 6 PRB for SA and 44 PRB for data in Freq. one SA occupies one PRB.	The SA and the associated data are transmitted in the same subframe.SA and data pool are FDMed, 6 PRB for SA and 44 PRB for data in Freq. one SA occupies one PRB.
Resource allocation principle		Sensing based resource selection - energy sensing, and the resource with least receiving energy is selected; Assuming UE enters	Random	Random	Random	Random	Random resource selection	Random resource selection

	NW one by one.						
Remark (e.g., communication range if traffic model2 is used for PC5 I2V, etc)	Shared resource pool						

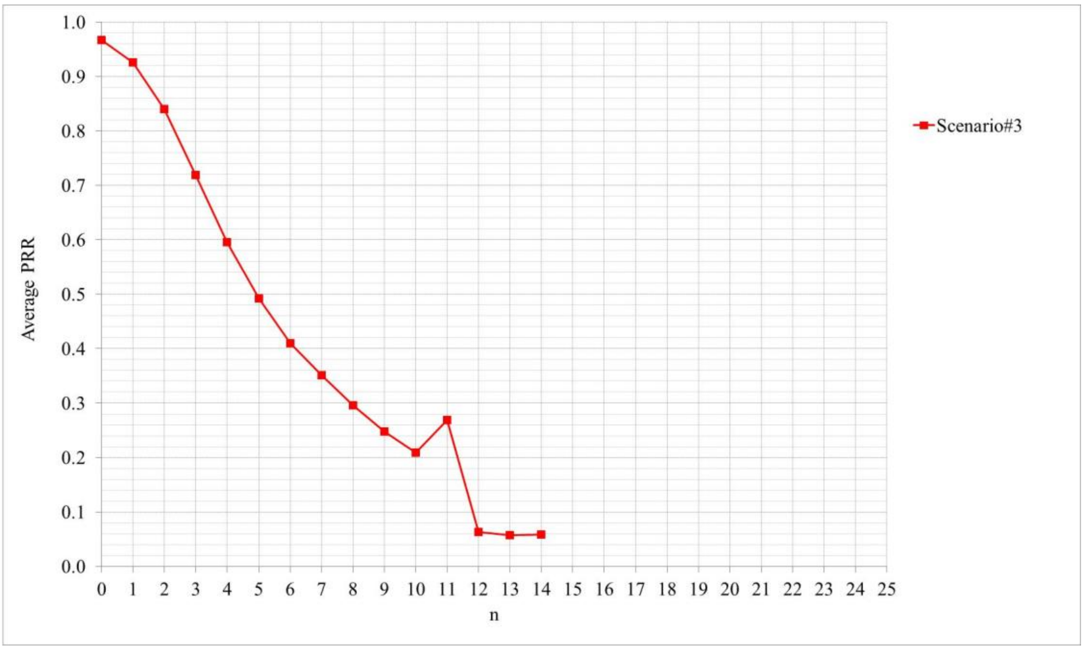
Description		**Source 15**
		Scenario#4
Carrier frequency (GHz)		6
Number of carriers		1 (10 MHz)
I2V Traffic model (e.g., model 1, 2)		Model 1
Number of subframes used to transmit each message	**190 bytes**	1
	300 bytes	1
Number of RBs used to transmit each message in each subframe	**190 bytes**	16RBs
	300 bytes	25RBs
Modulation	**190 bytes**	QPSK
	300 bytes	QPSK

Transmission power (in case of non-zero MPR, actual power after applying MPR)	23dBm
Physical channel format (e.g., RS)	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data
MPR and inband emission model	{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843
Synchronization assumptions	Ideal time synchronization and frequency offset
SA assumption (e.g., SA overhead)	The SA and the associated data are transmitted in the same subframe.SA and data pool are FDMed, 6 PRB for SA and 44 PRB for data in Freq. one SA occupies one PRB.
Resource allocation principle	Random resource selection
Remark (e.g., communication range if traffic model2 is used for PC5 I2V, etc)	

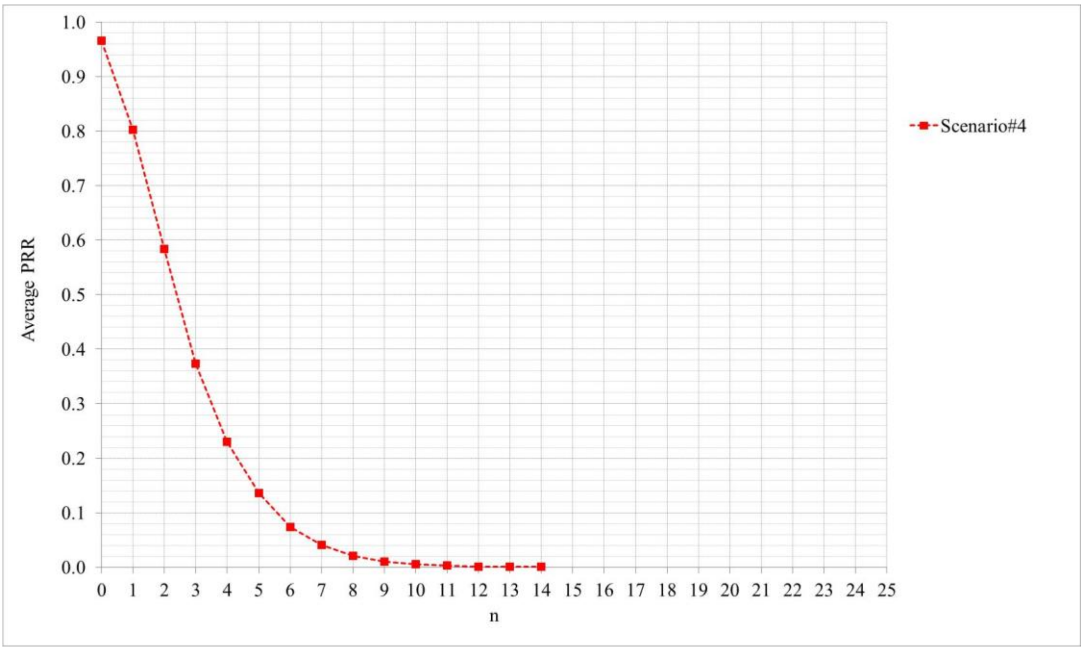
E.2 Simulation results

Average PRR of each source is as follows (a=n*20 m, b=(n+1)*20 m):

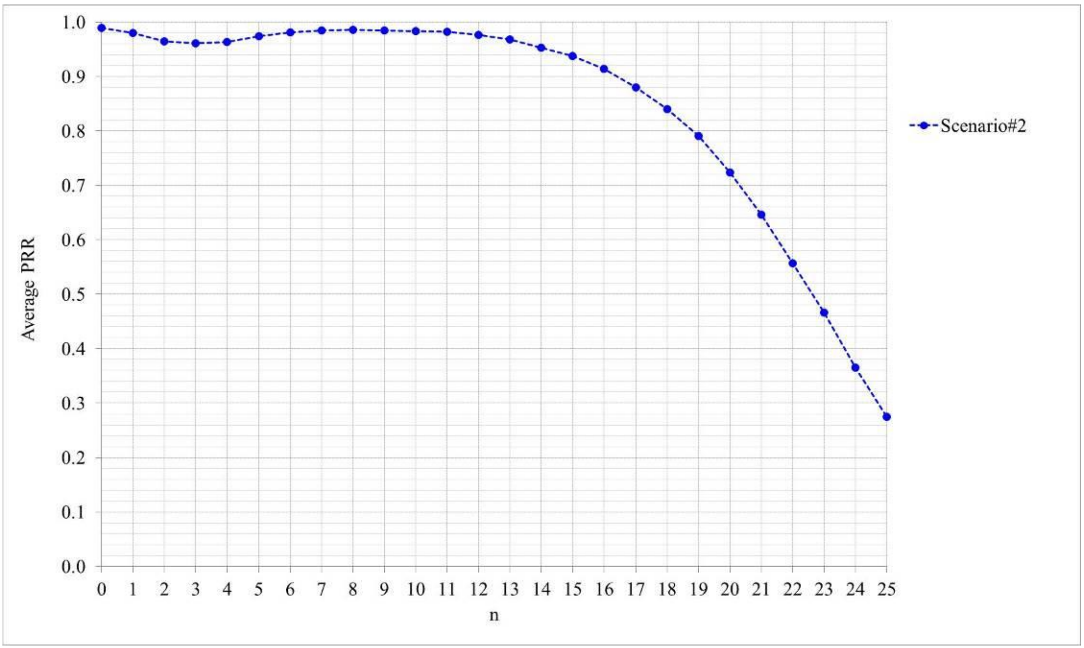
- V-UE RX of V-UE TX without UE type RSU TX
    - Source 1



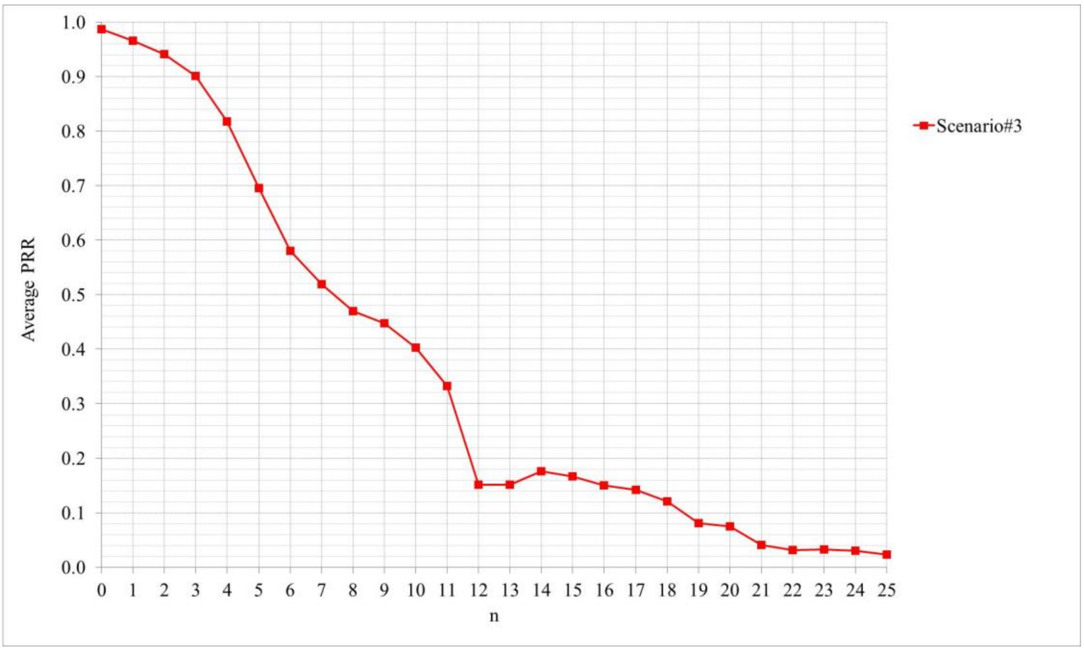
    - Source 2



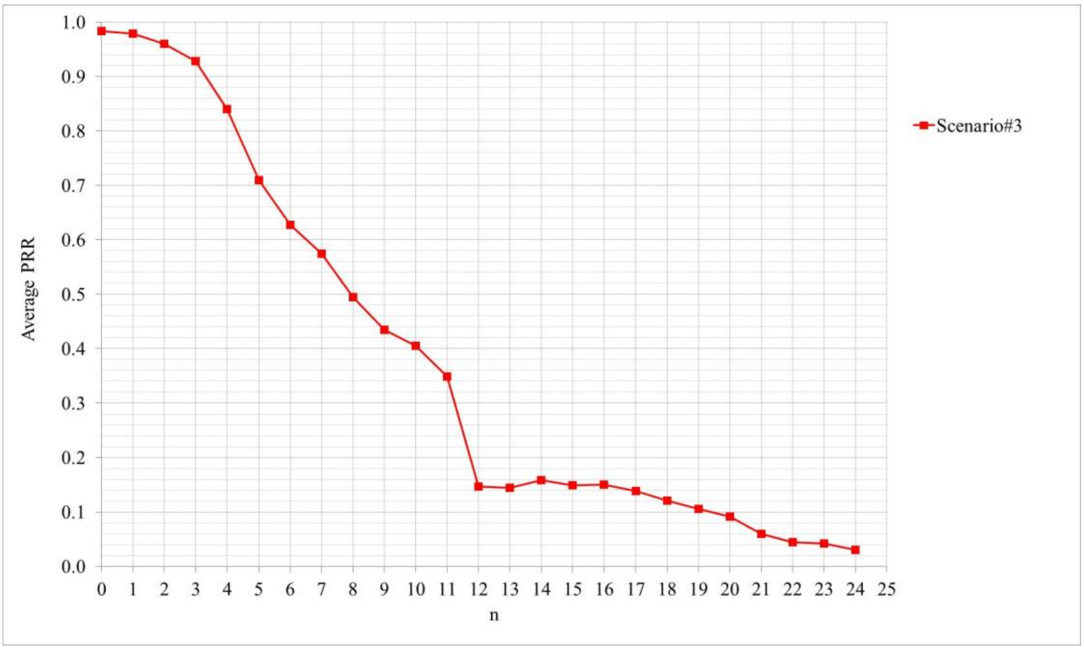
    - Source 3



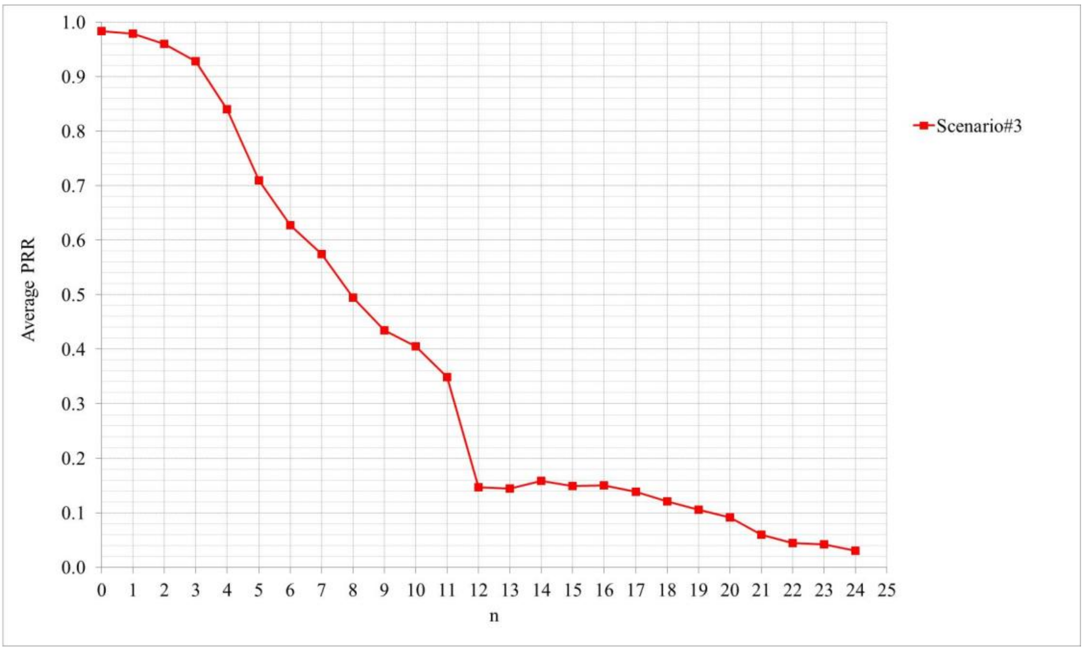
- Source 4



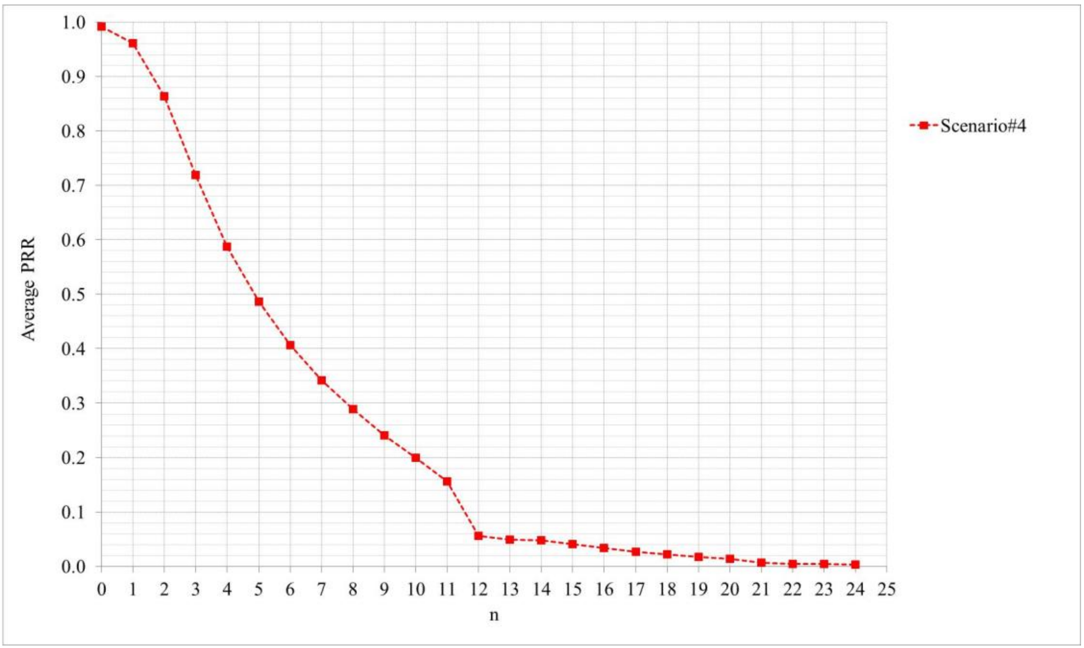
- Source 5



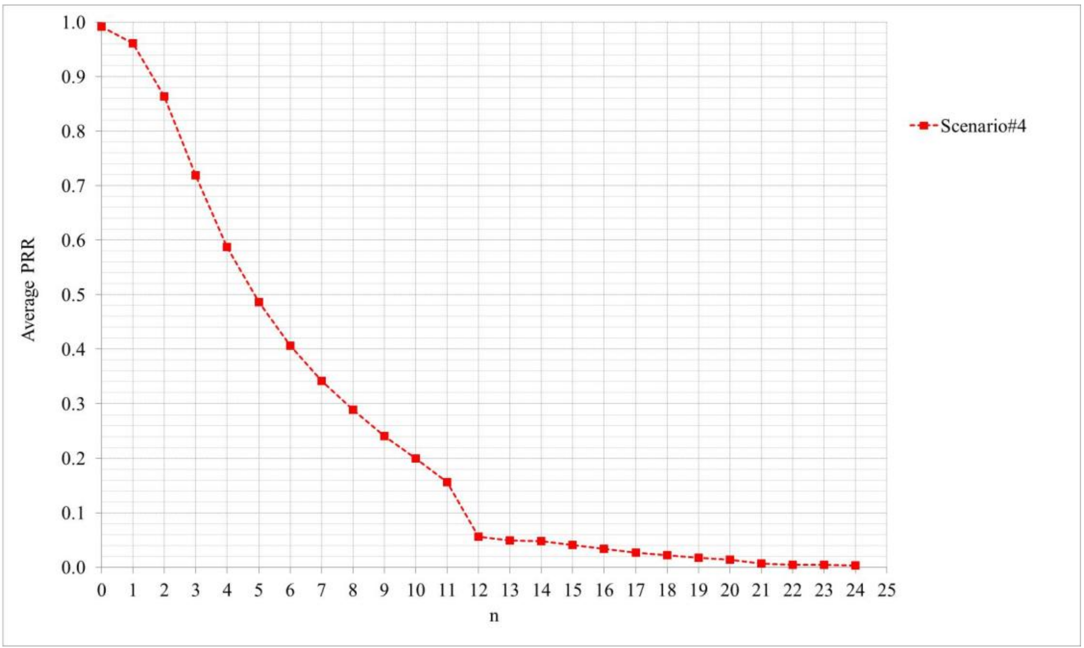
- Source 6



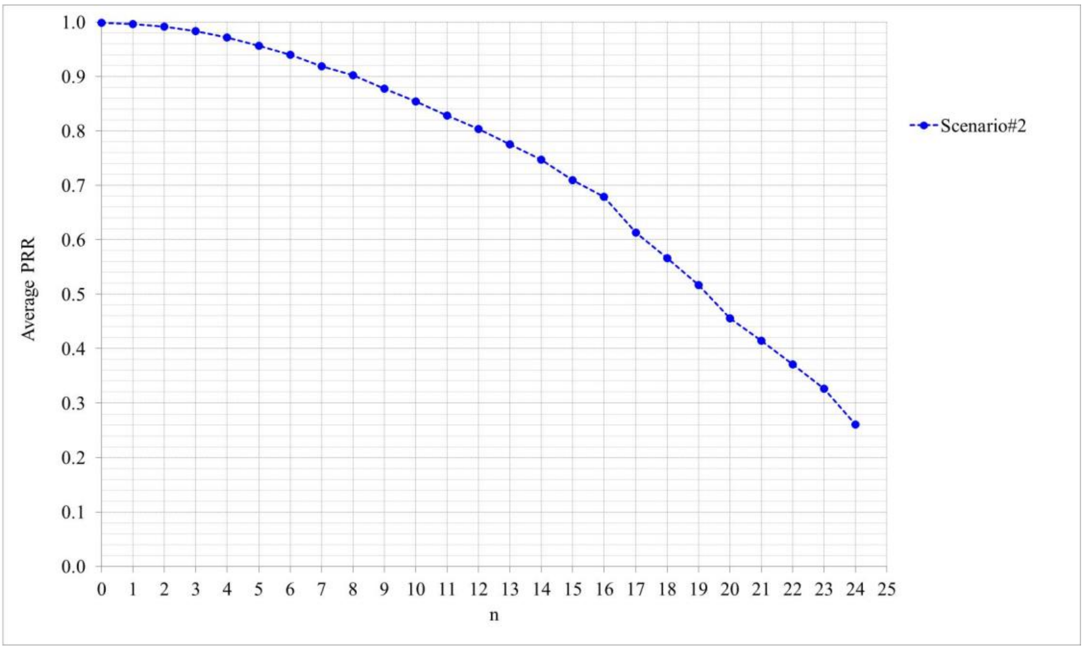
- Source 7



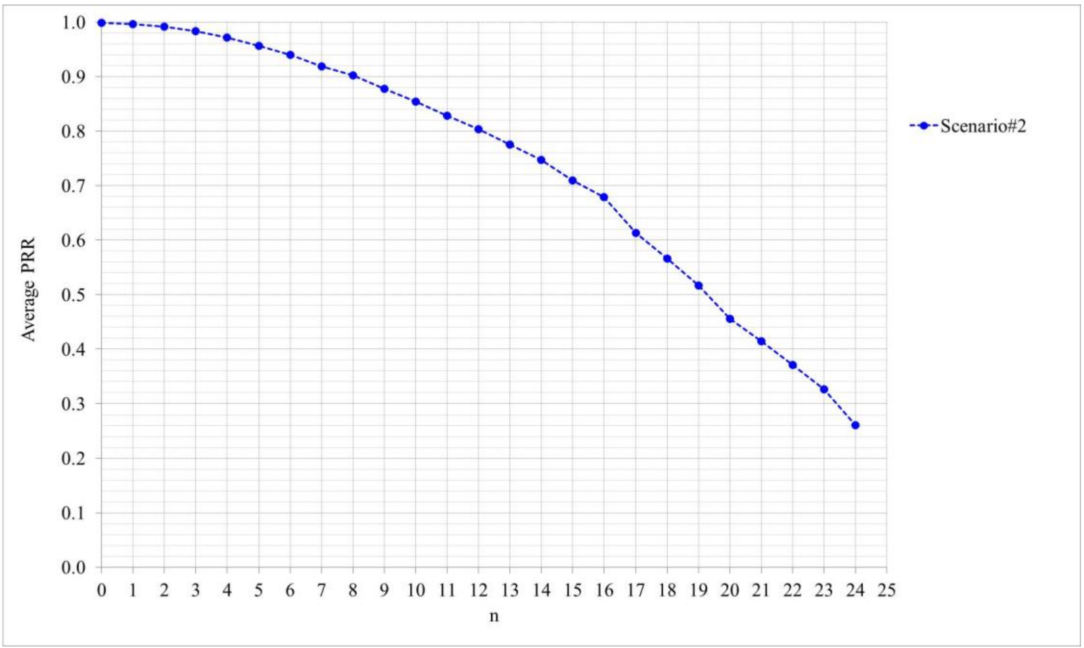
- Source 8



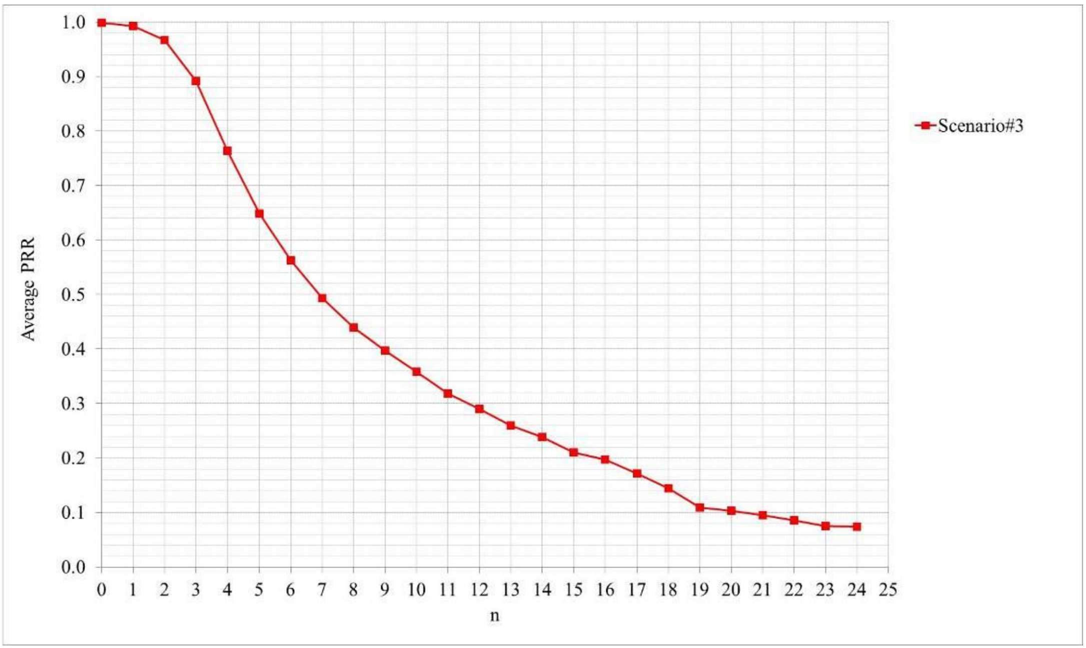
- Source 9



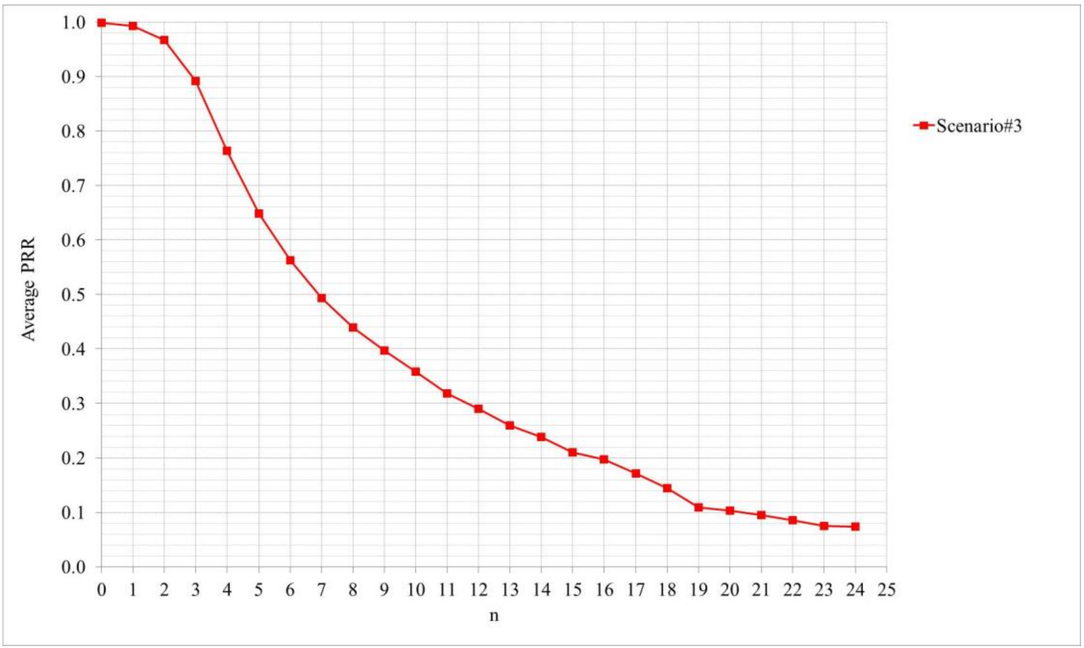
- Source 10



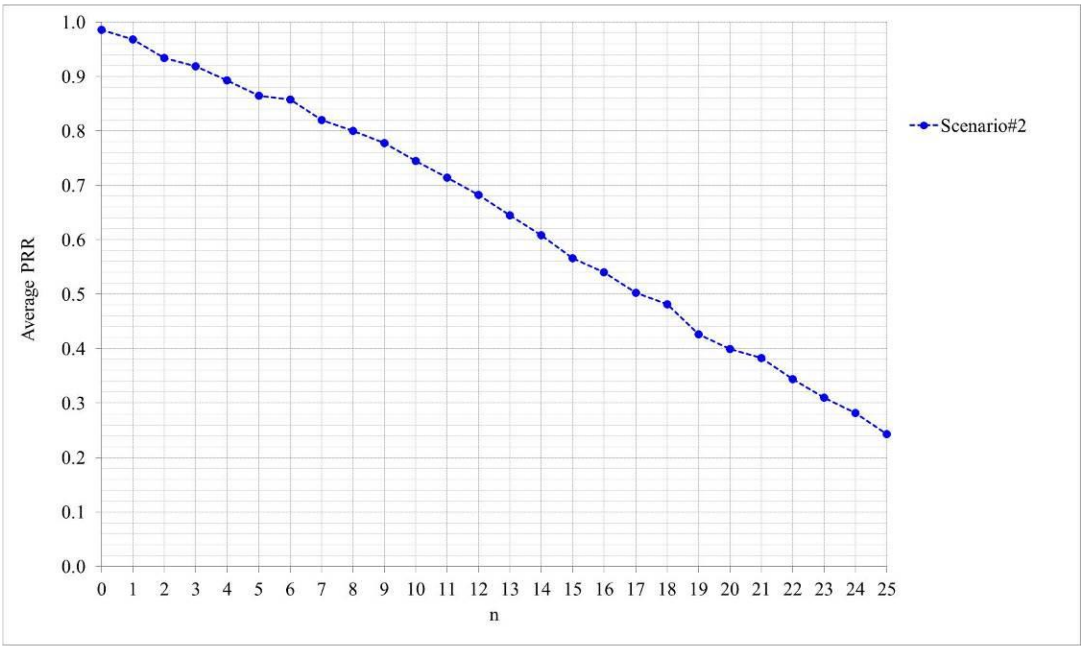
- Source 11



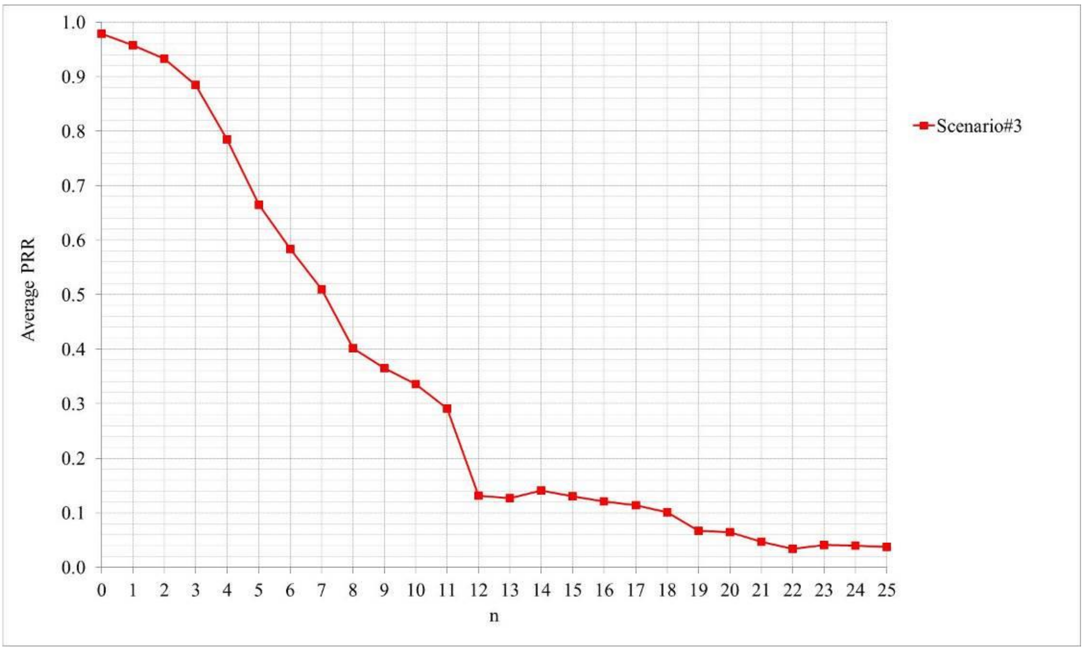
- Source 12



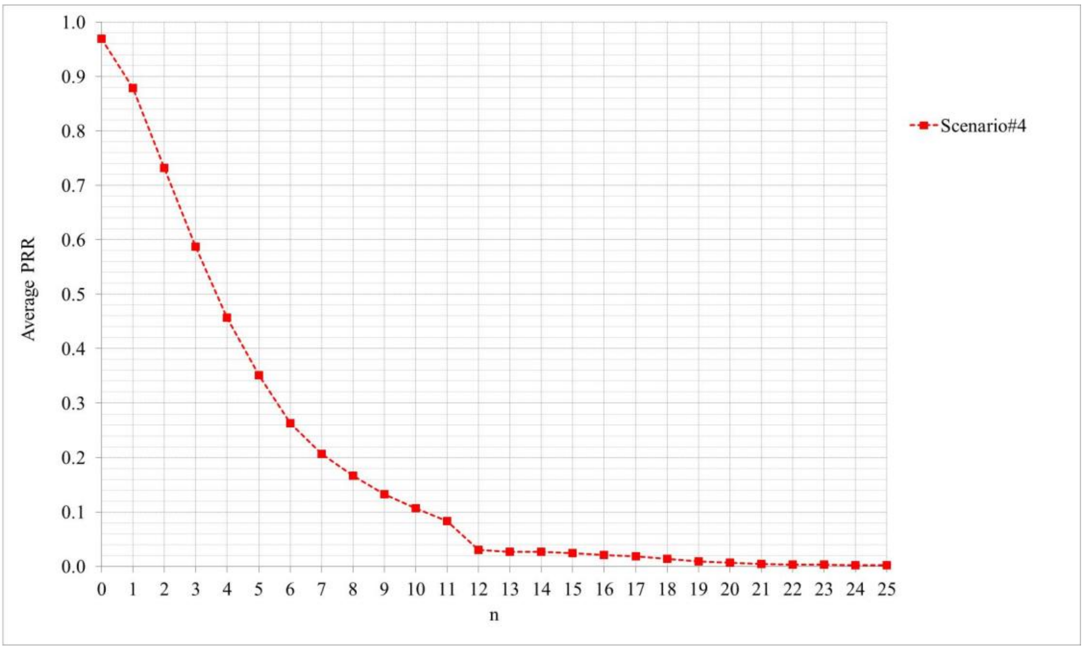
- Source 13



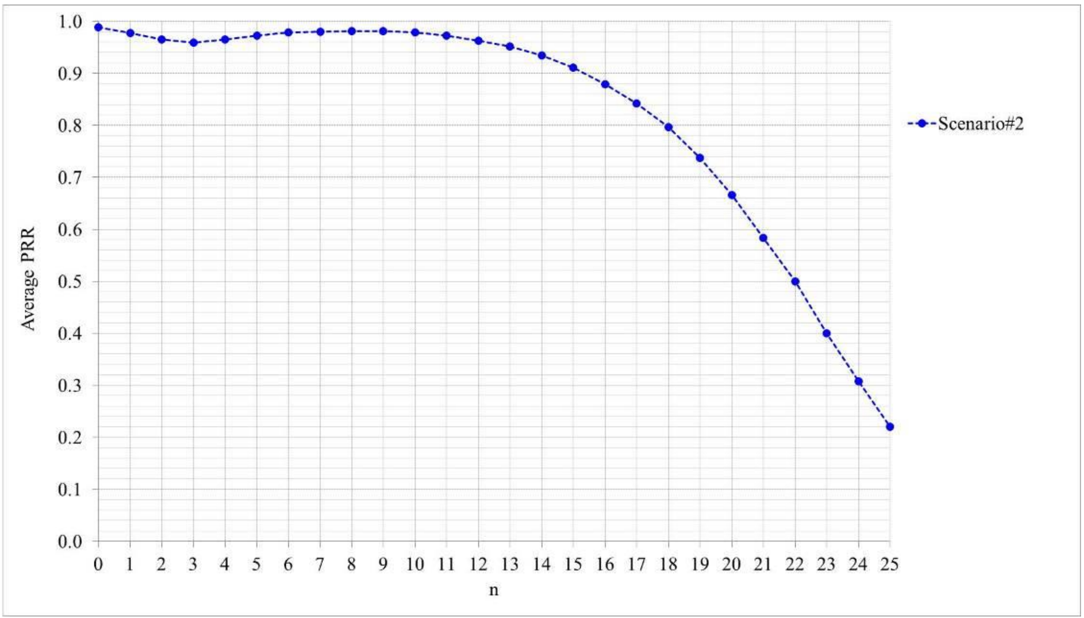
• Source 14



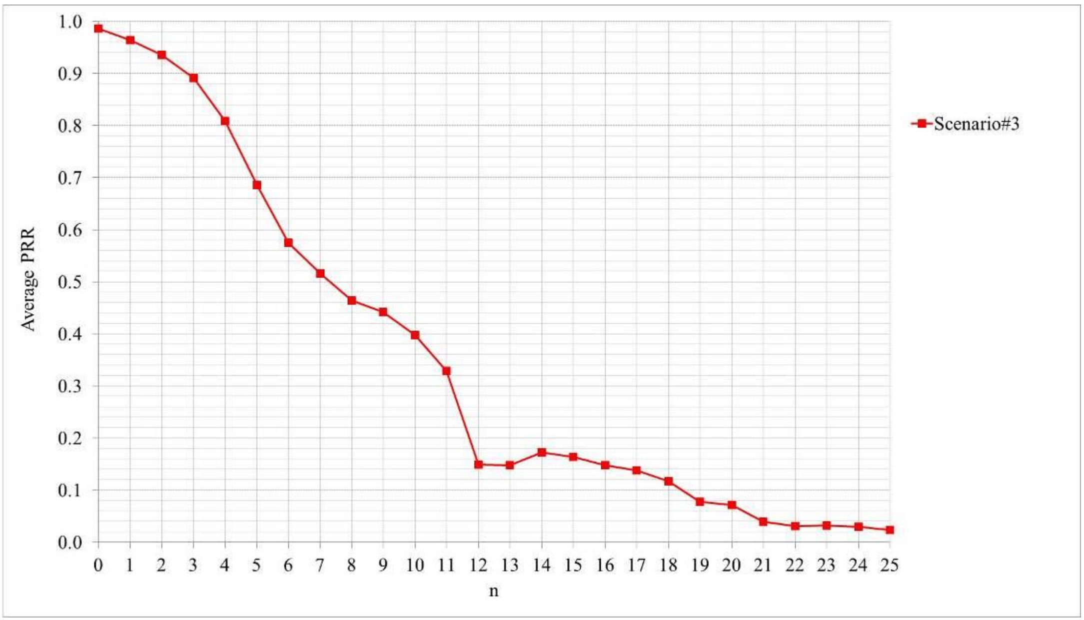
• Source 15



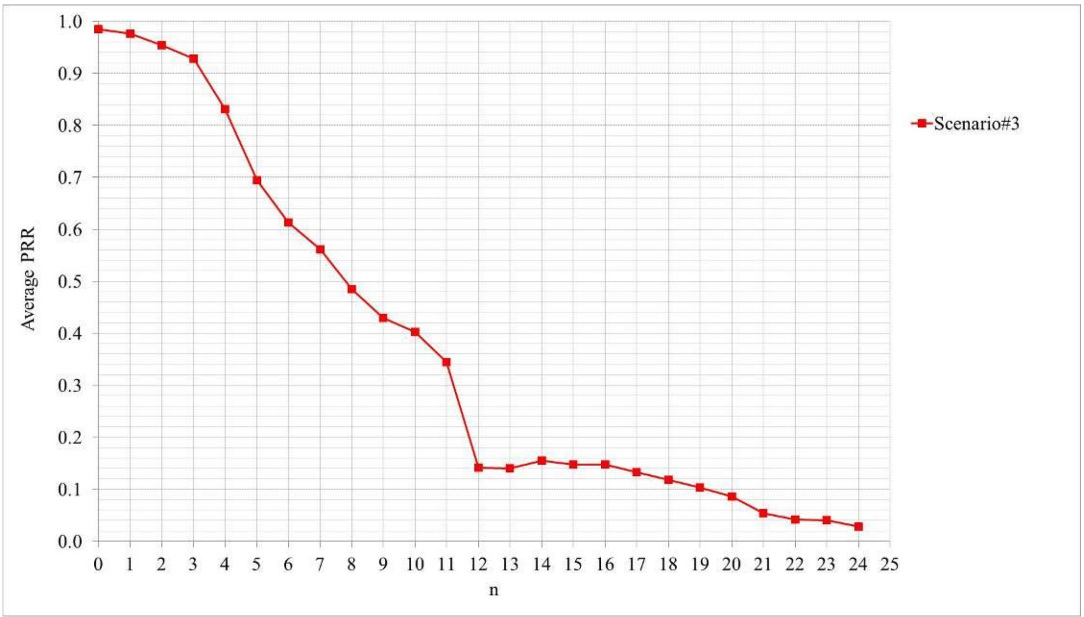
- V-UE RX of V-UE TX with UE type RSU TX
    - Source 3



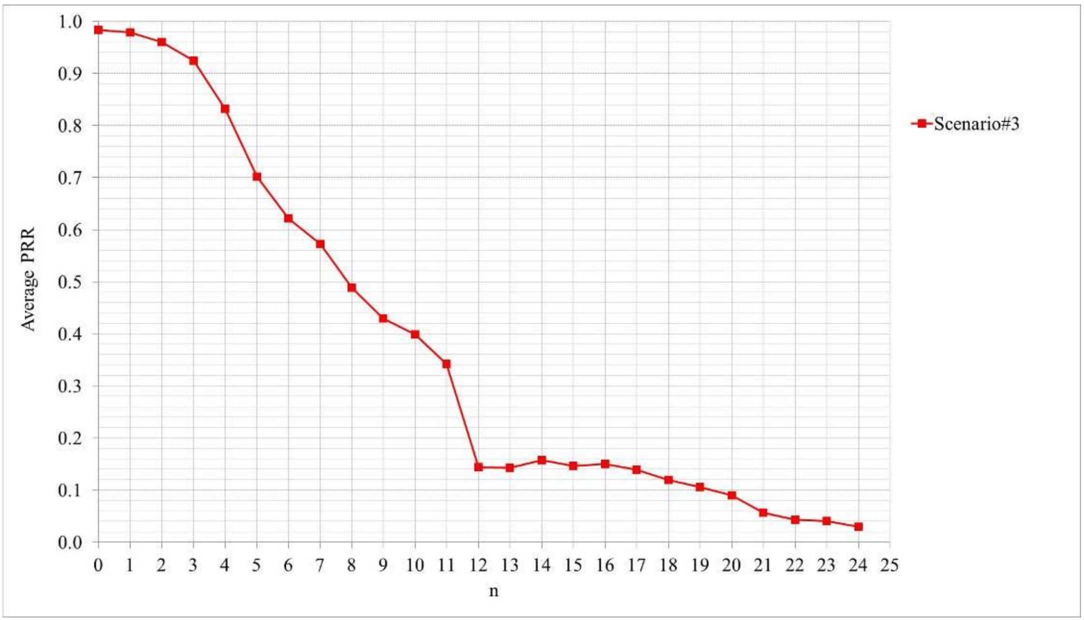
    - Source 4



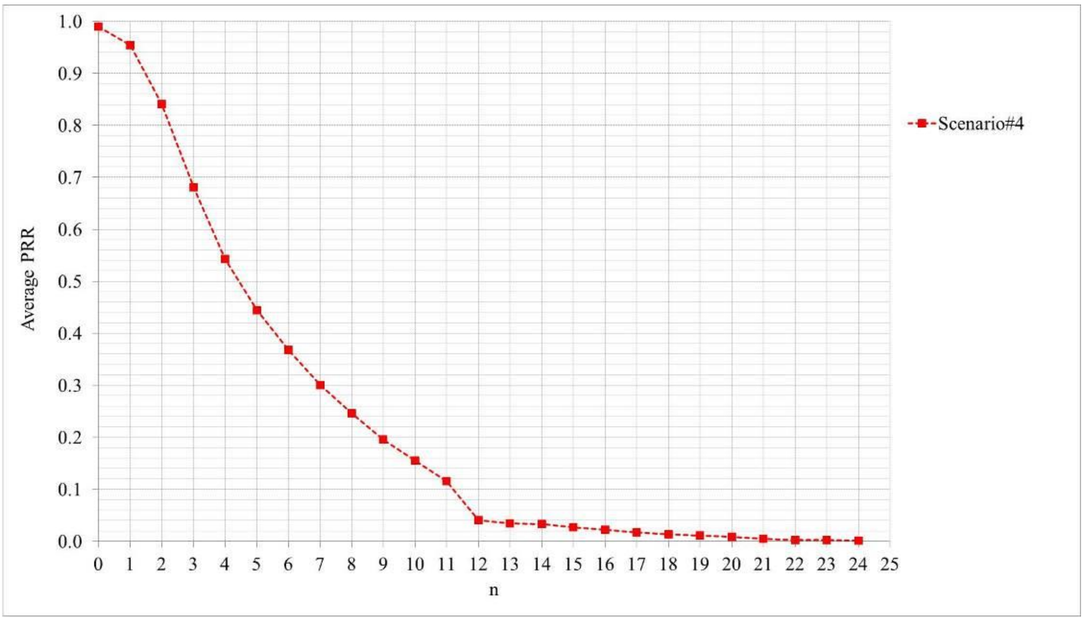
- Source 5



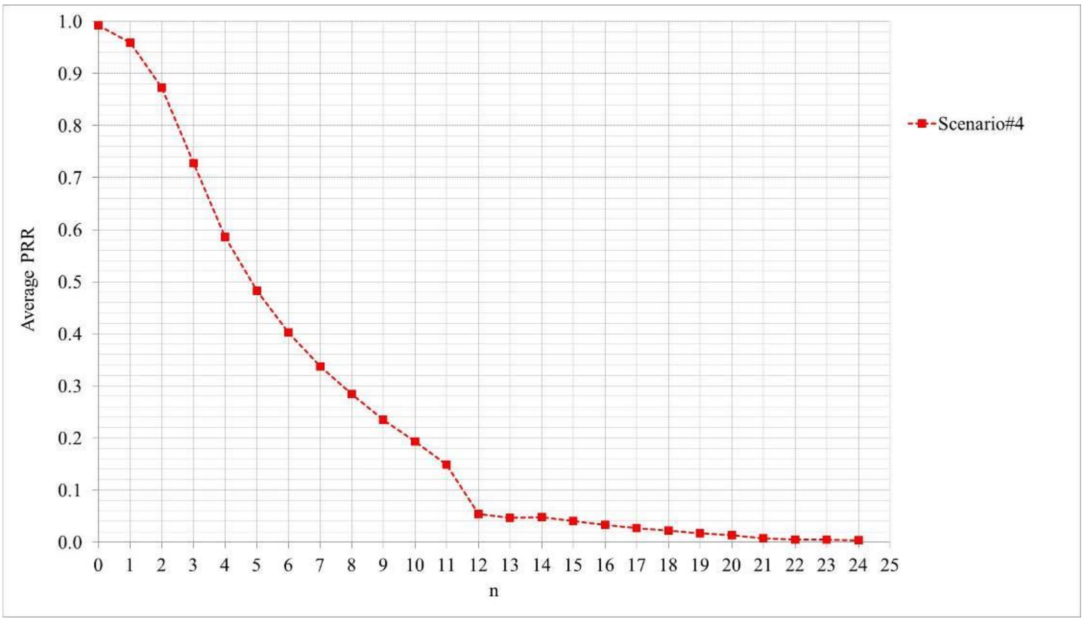
- Source 6



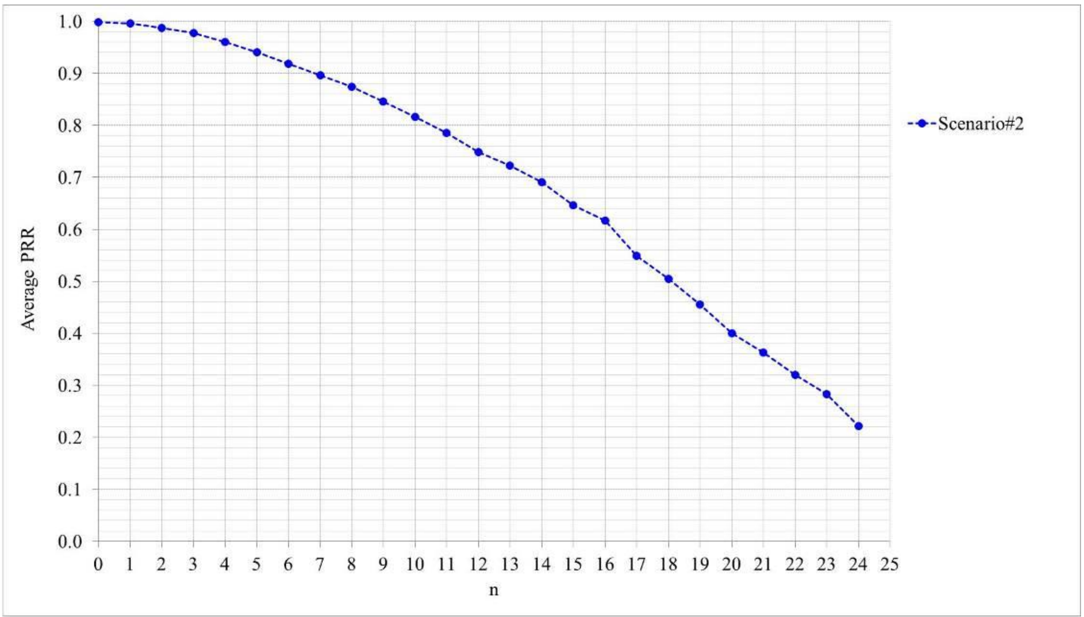
- Source 7



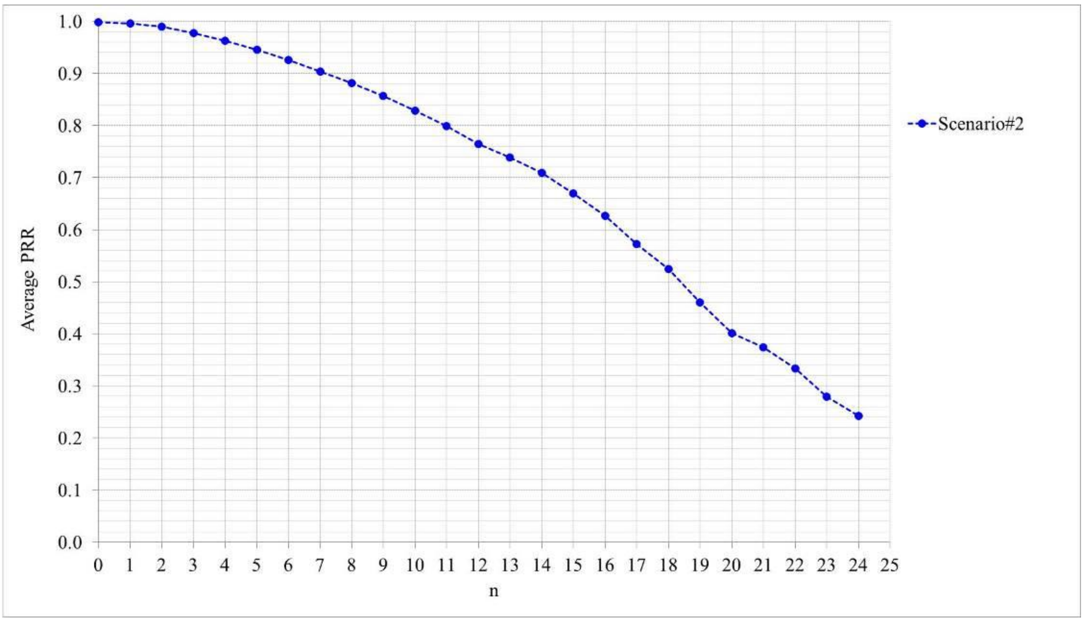
- Source 8



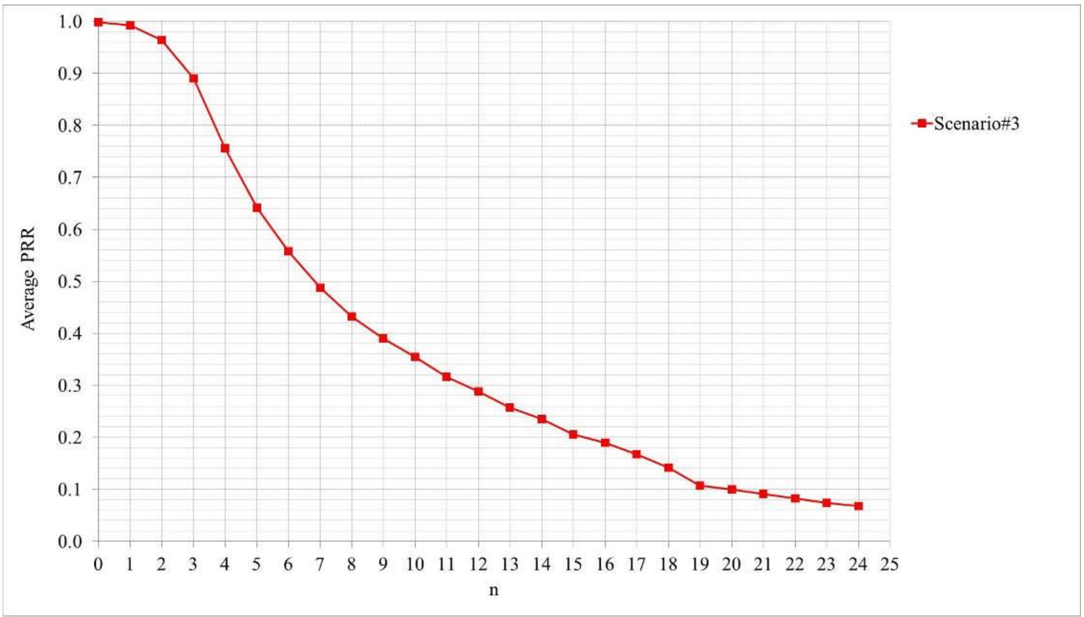
- Source 9



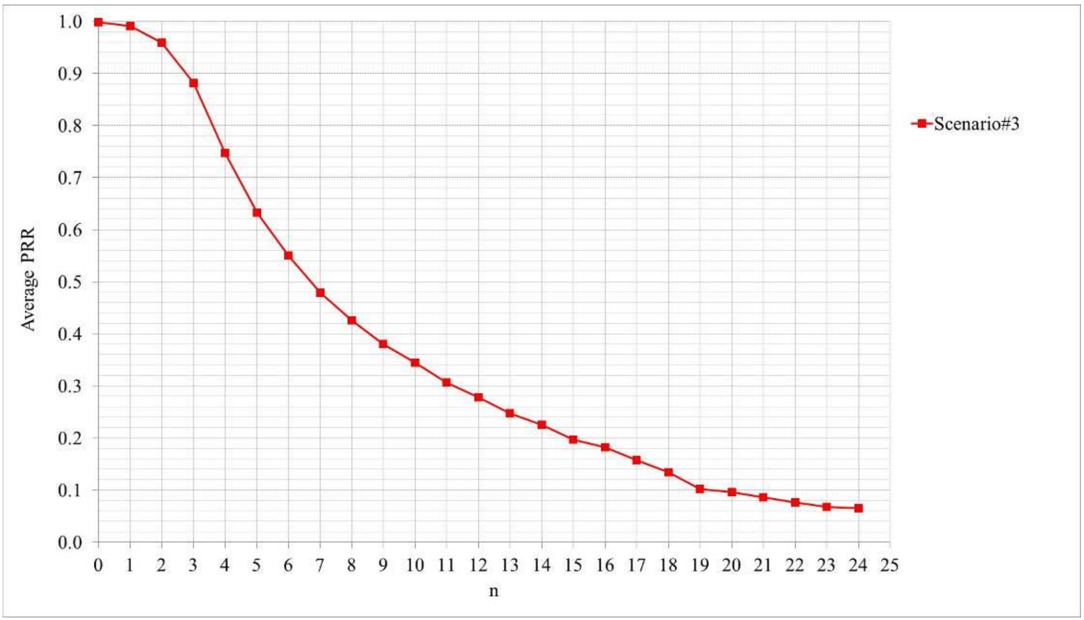
- Source 10



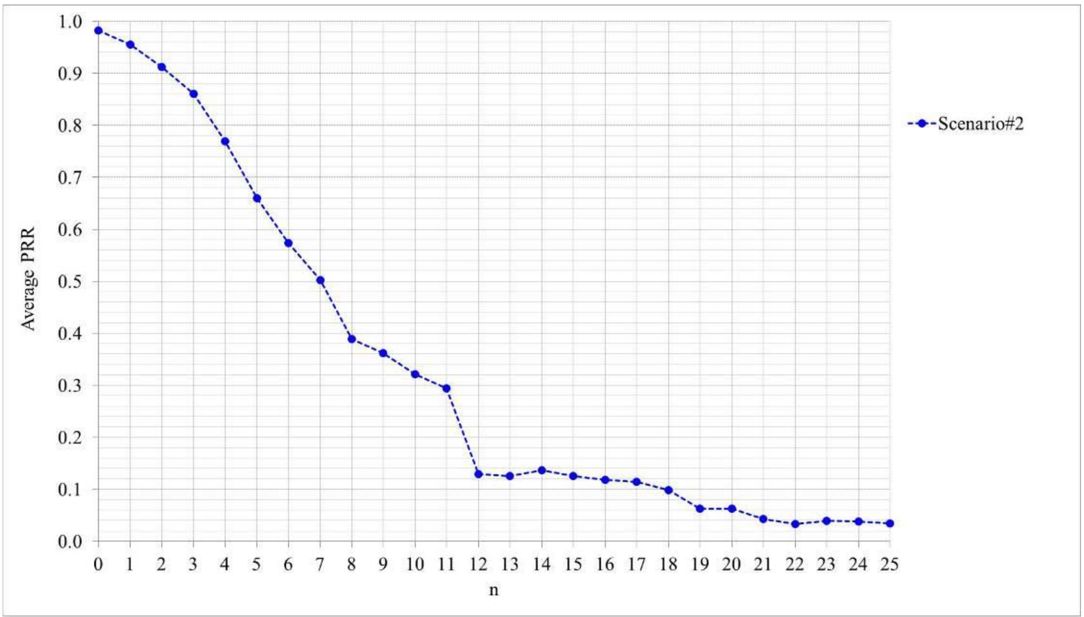
- Source 11



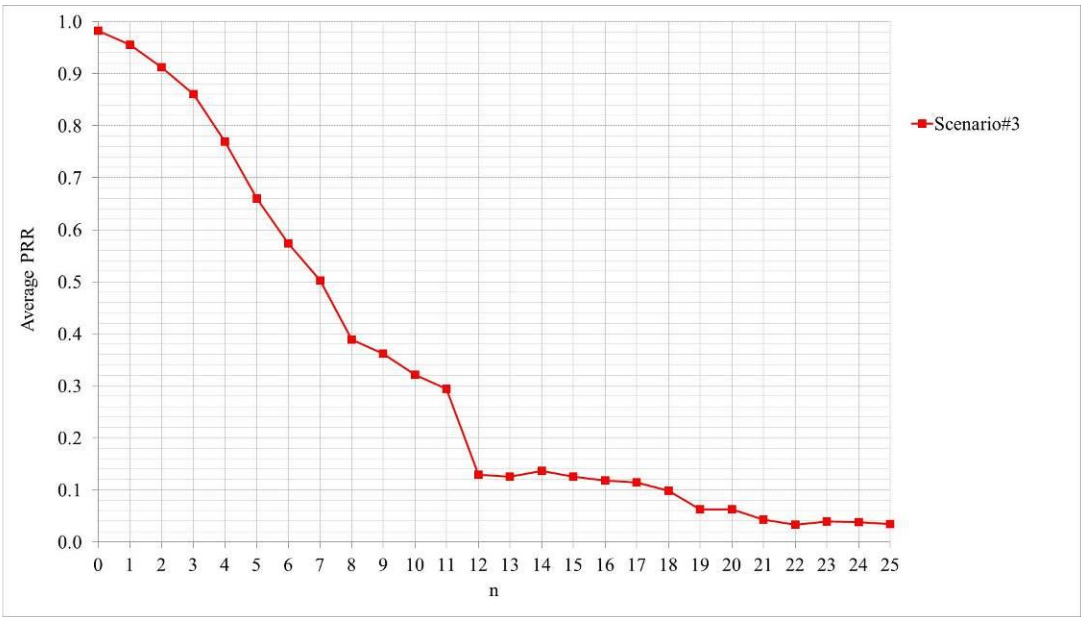
- Source 12



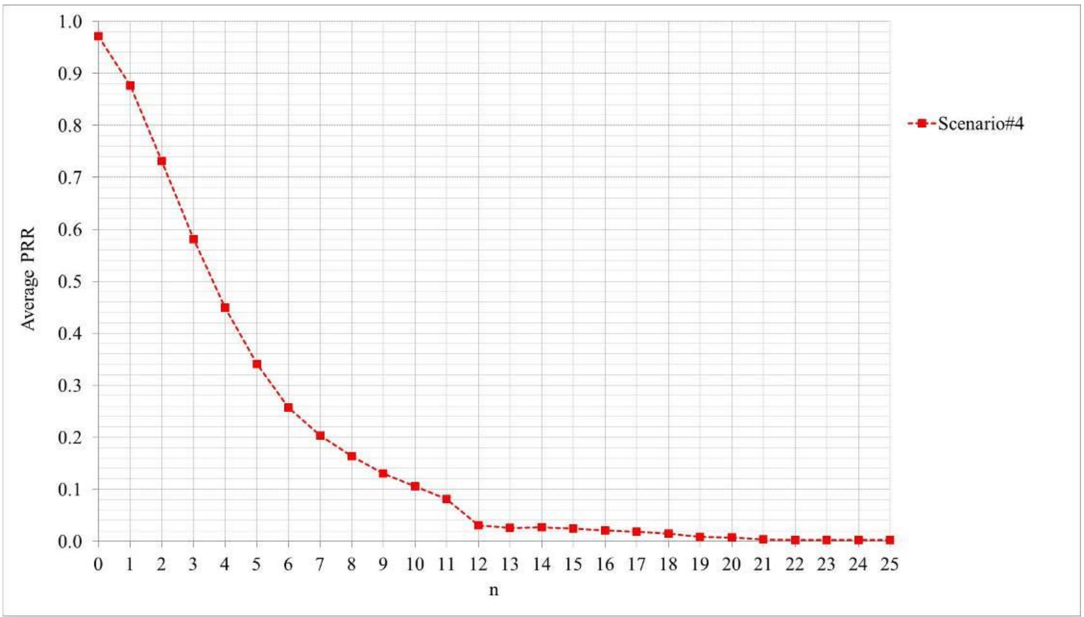
- Source 13



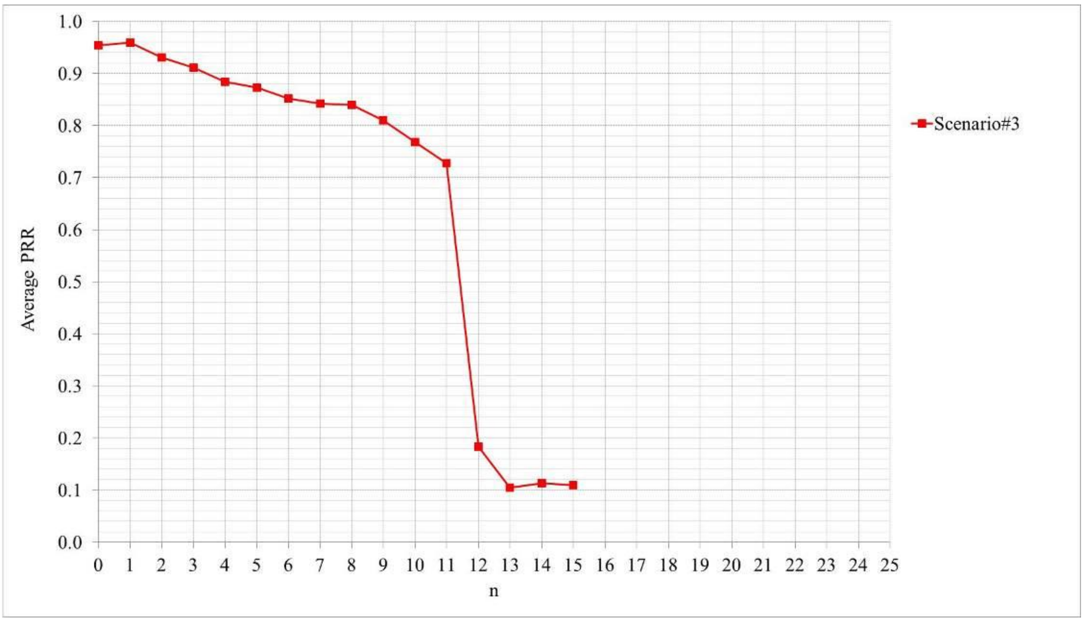
- Source 14



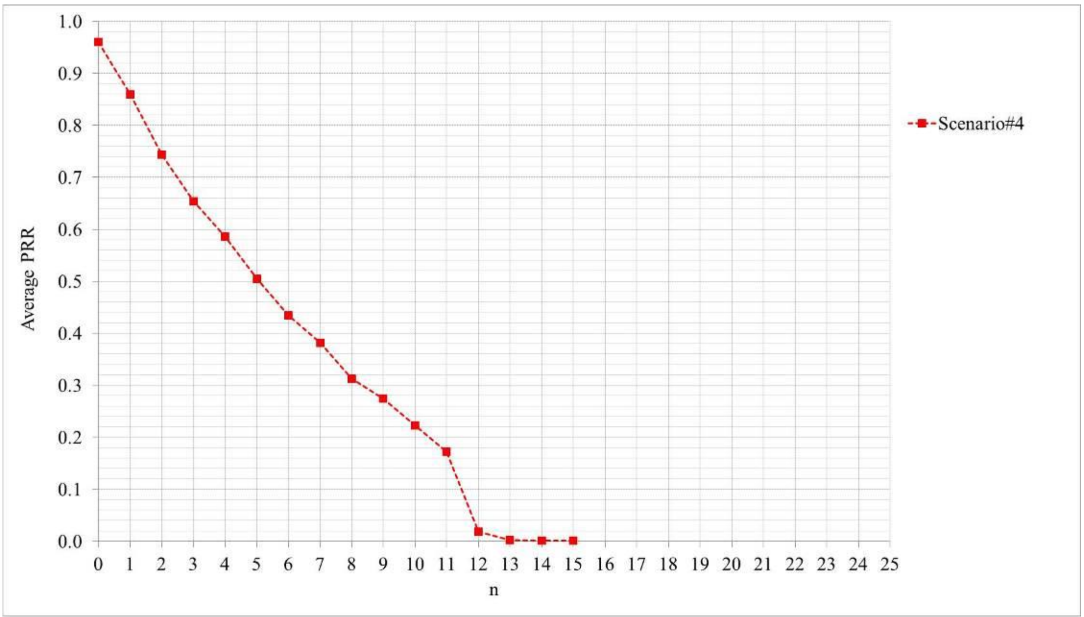
- Source 15



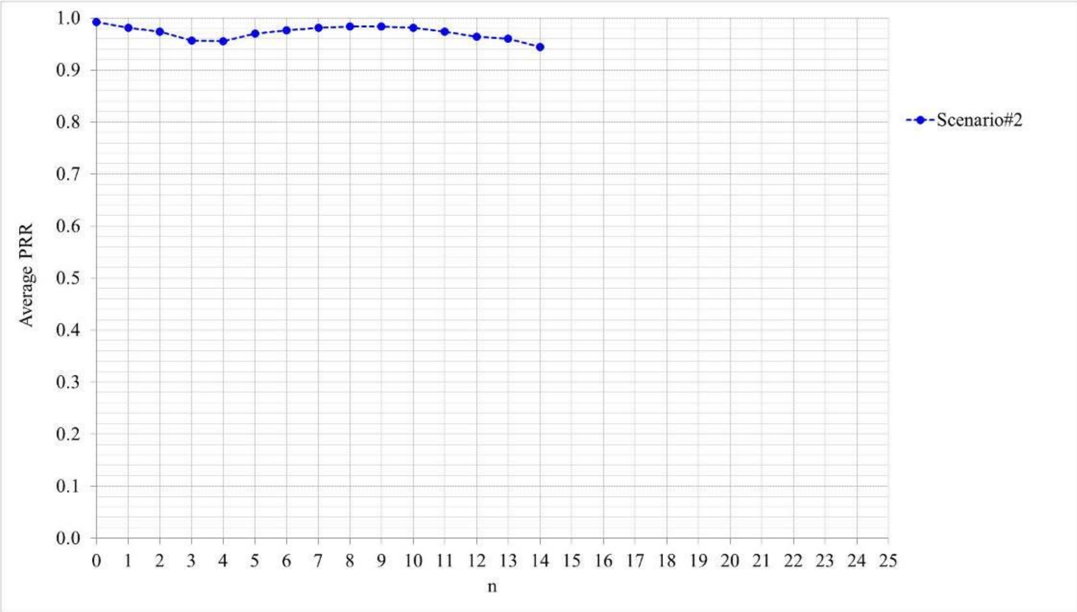
- V-UE RX of UE type RSU TX with V-UE TX
    - Source 1



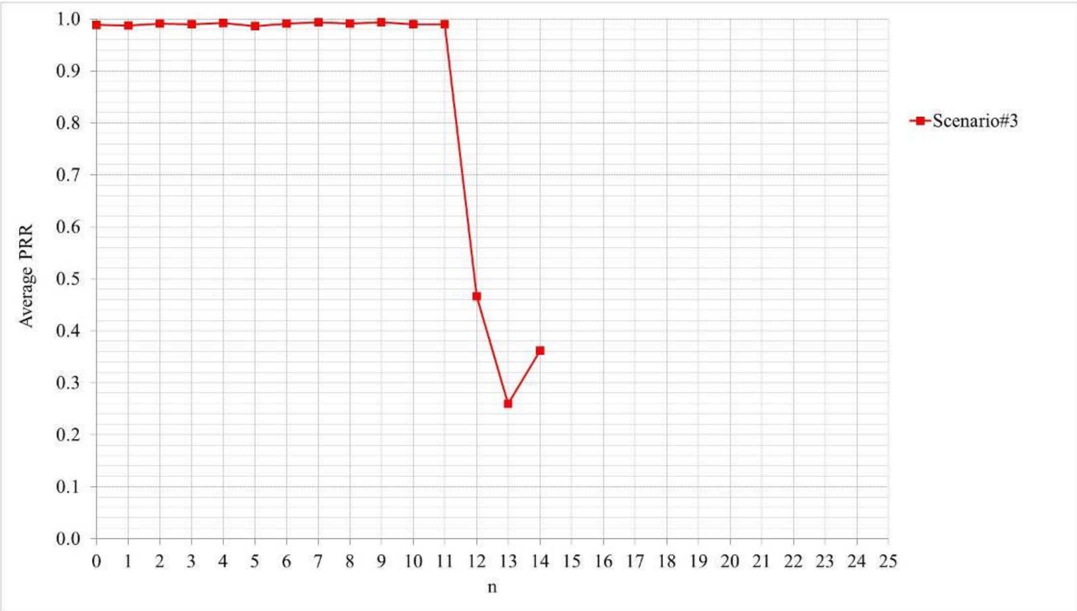
- Source 2



- Source 3



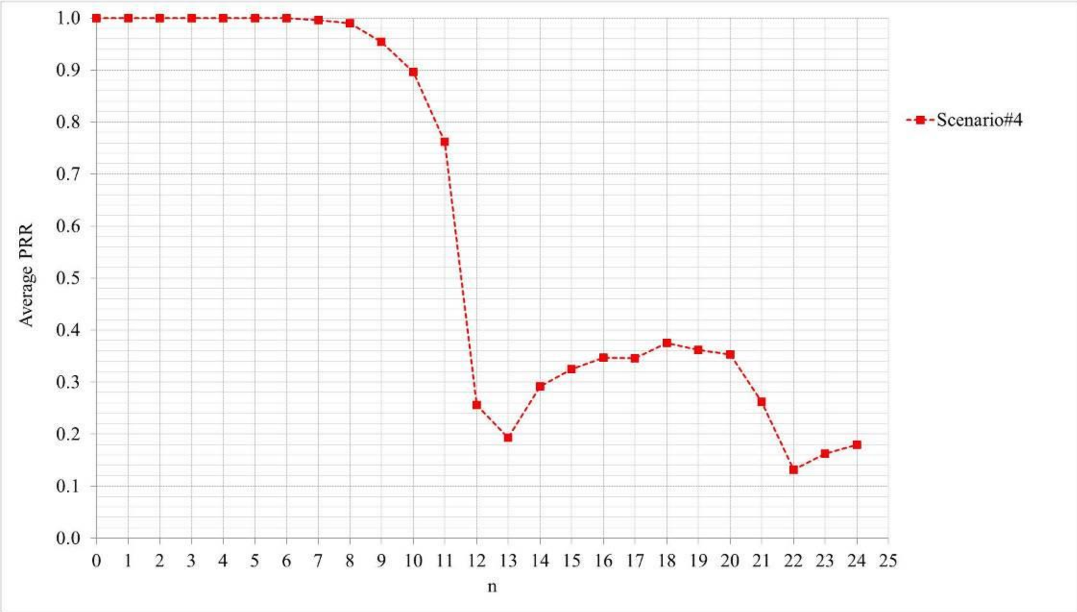
- Source 4



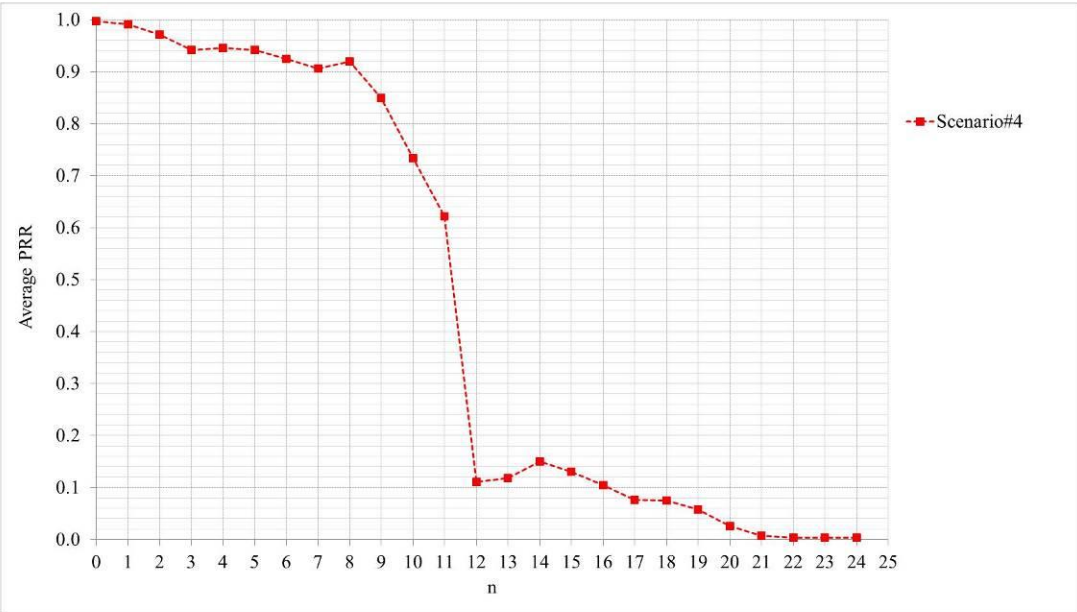
- Source 5

- Source 6

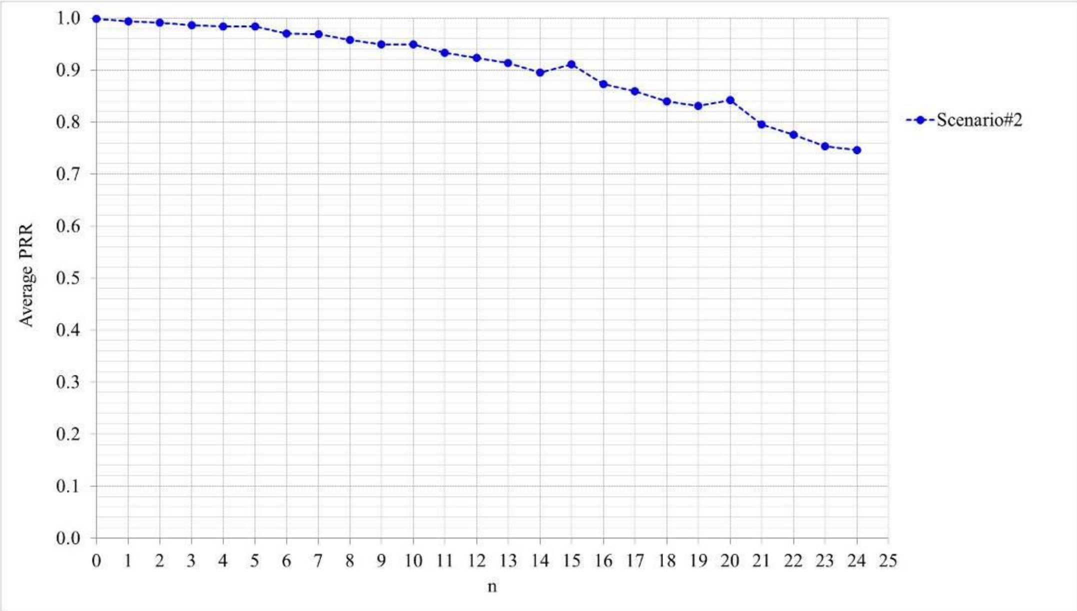
- Source 7



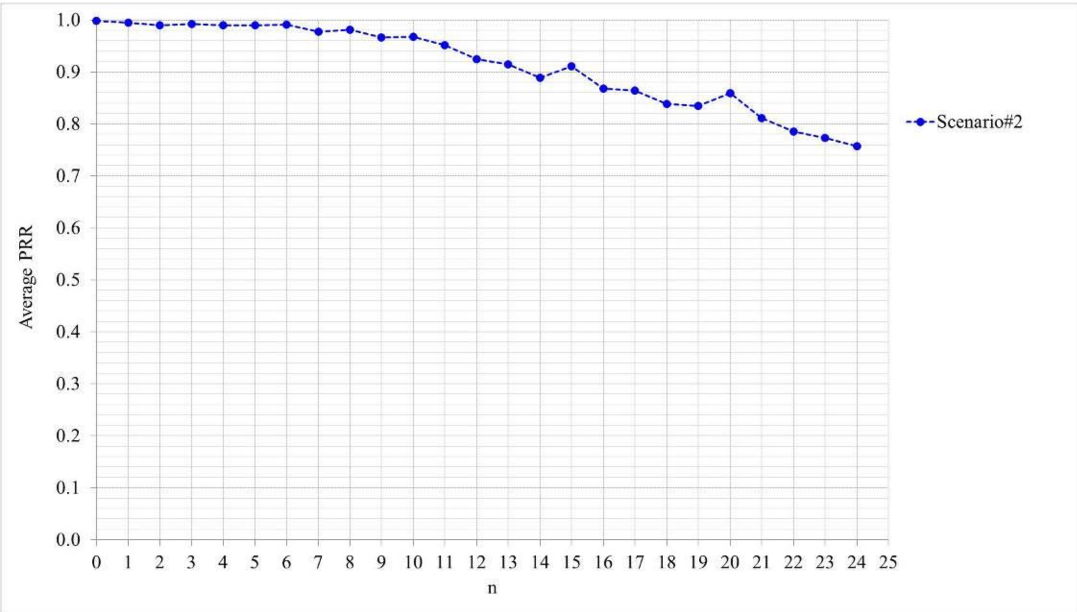
- Source 8



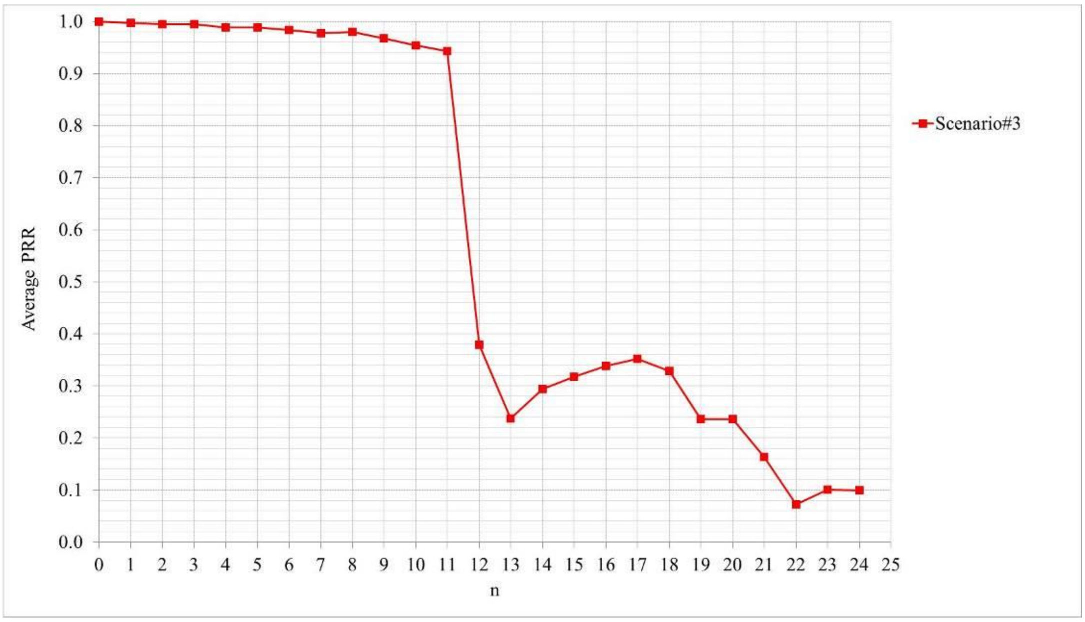
- Source 9



- Source 10

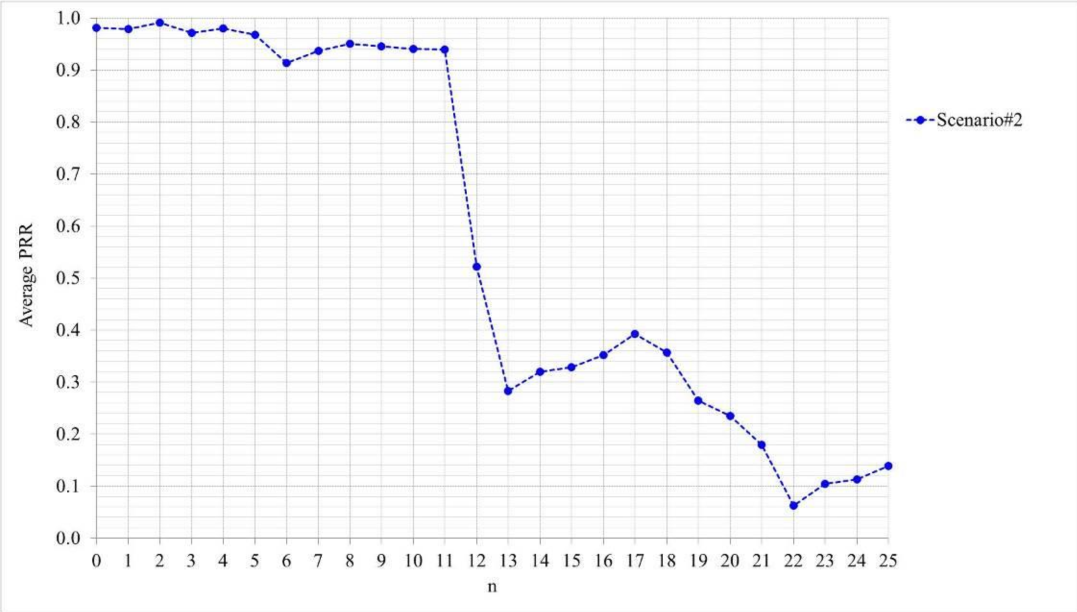


- Source 11

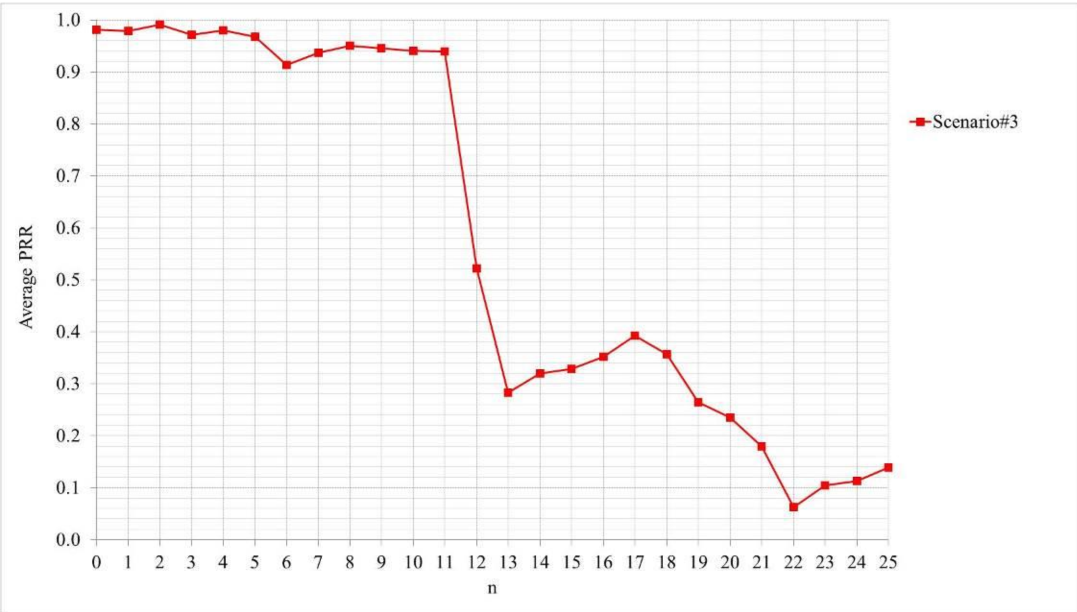


- Source 12

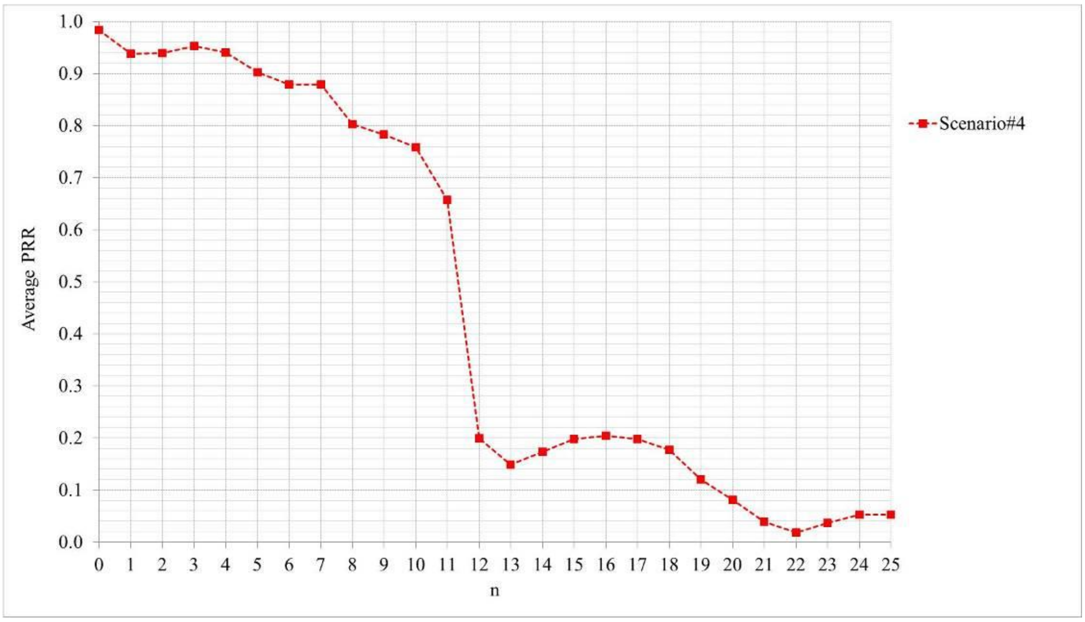
- Source 13



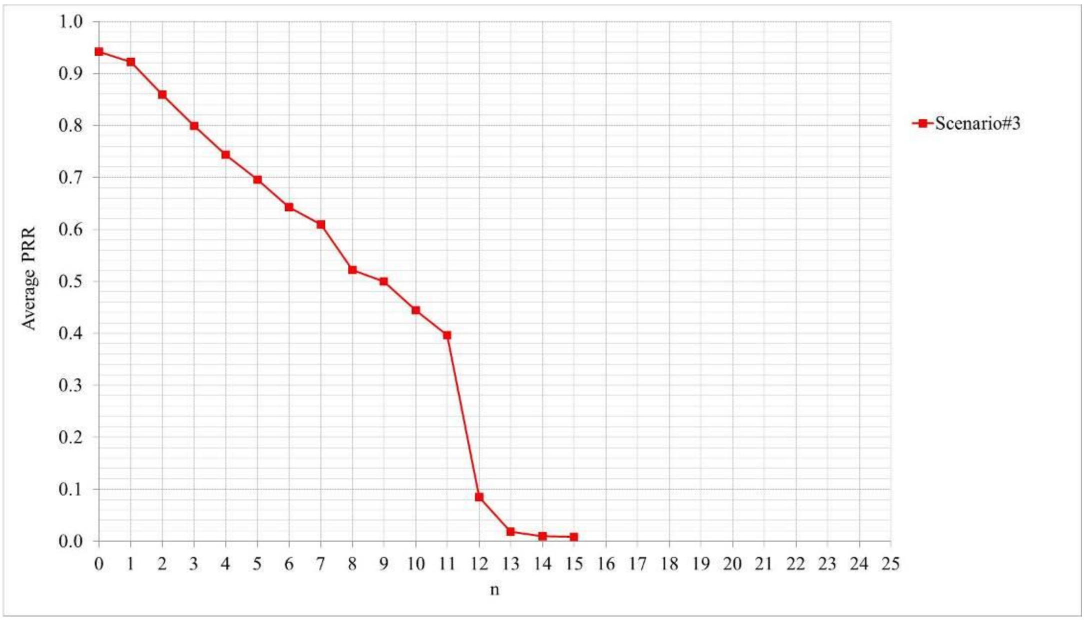
- Source 14



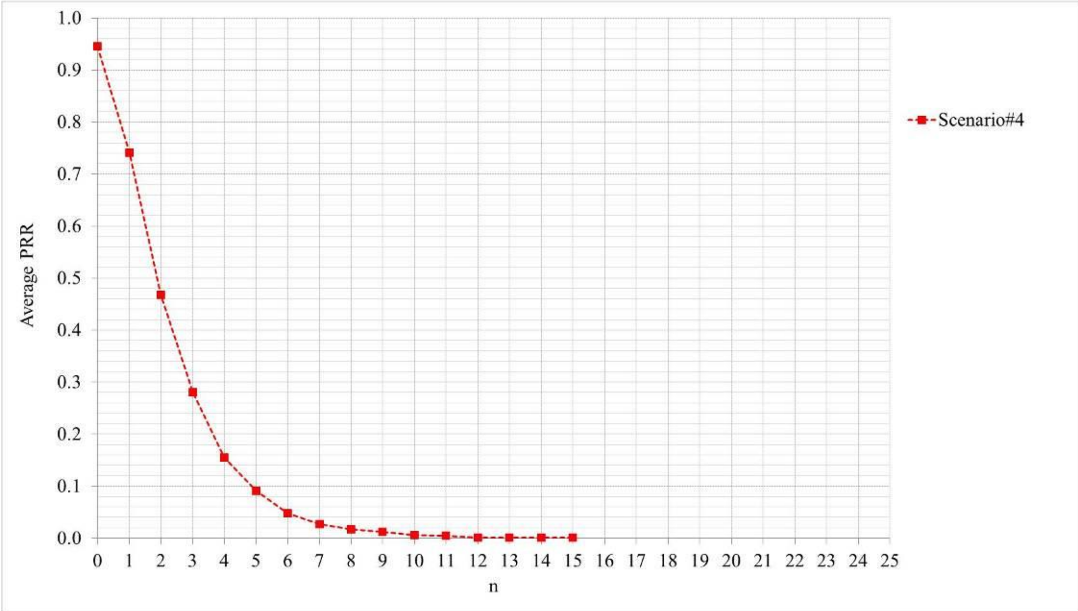
- Source 15



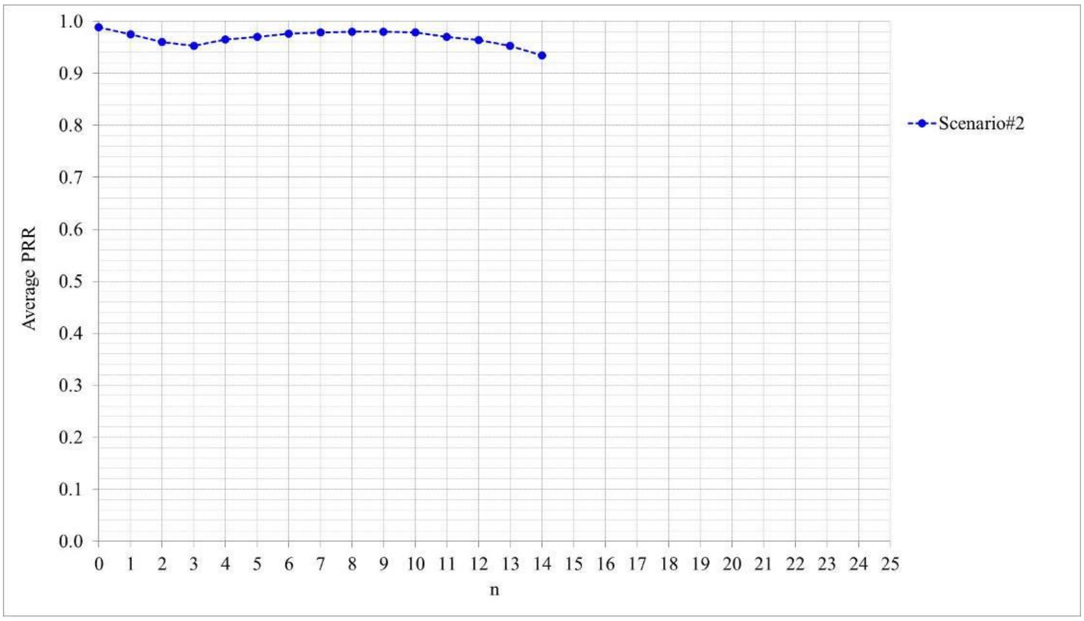
- UE type RSU RX of V-UE TX with UE type RSU TX
    - Source 1



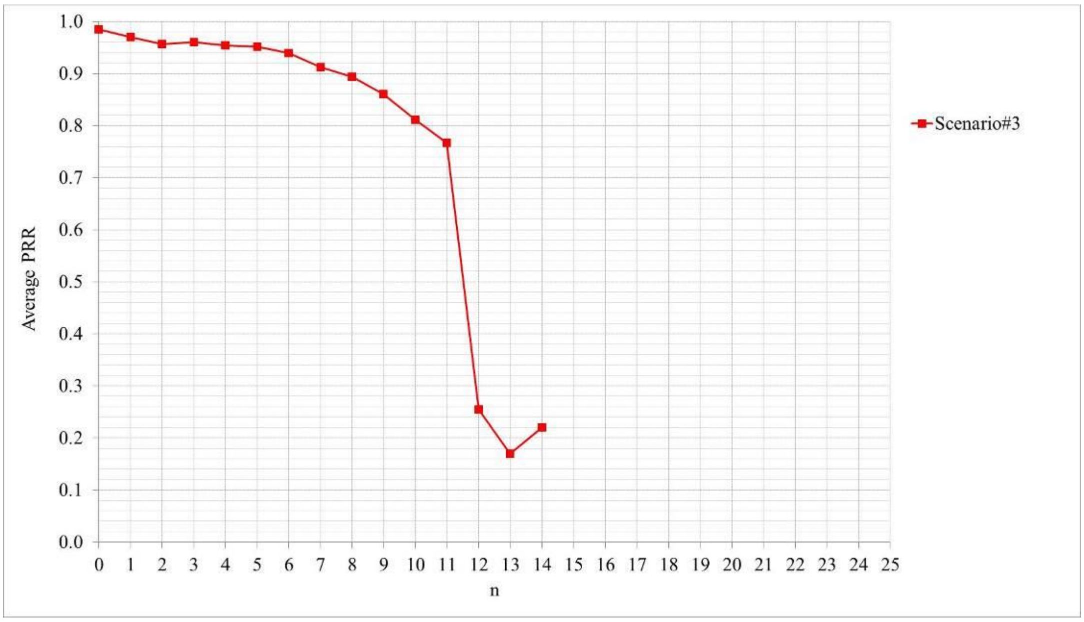
- Source 2



- Source 3

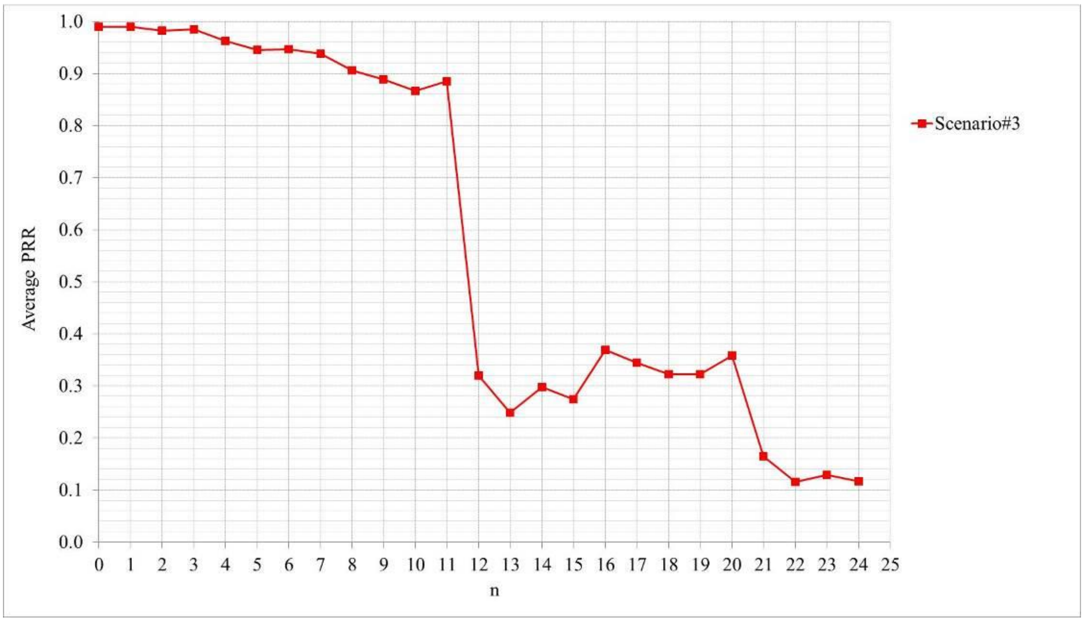


- Source 4

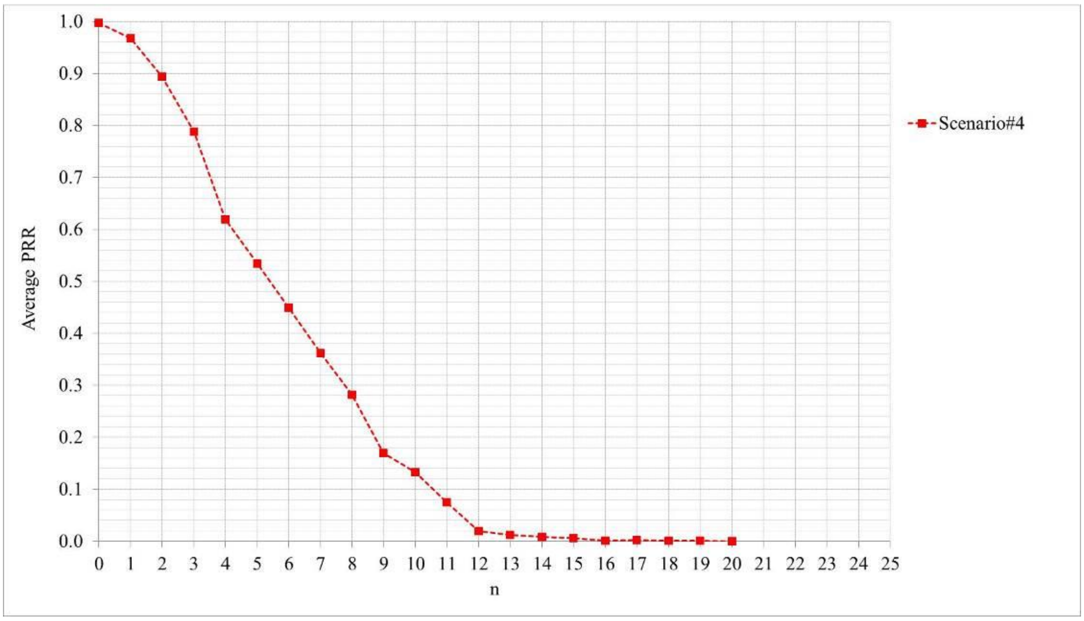


- Source 5

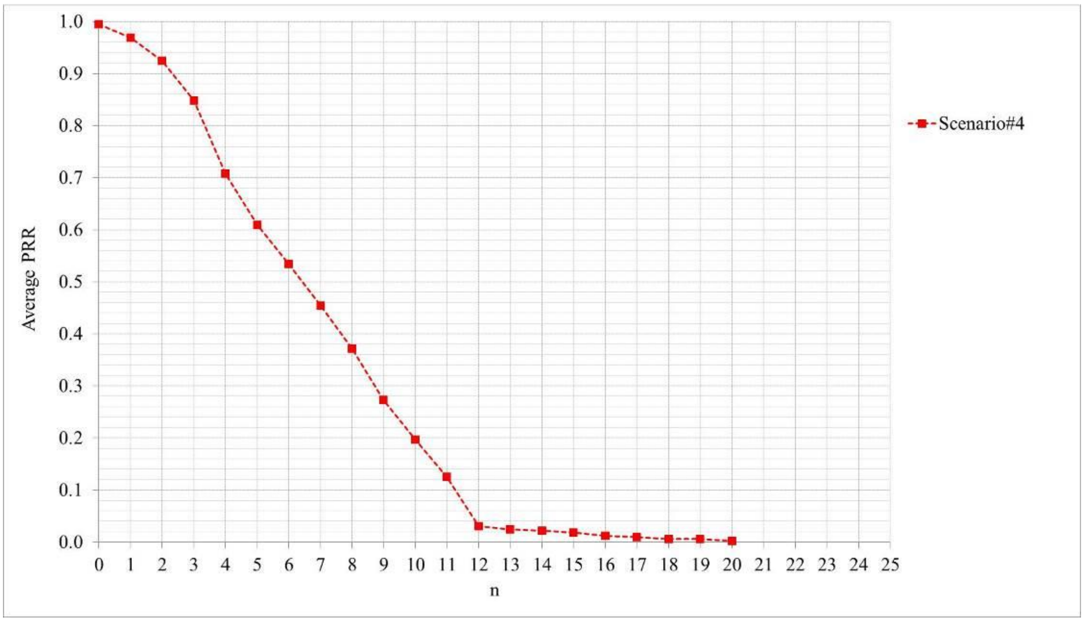
- Source 6



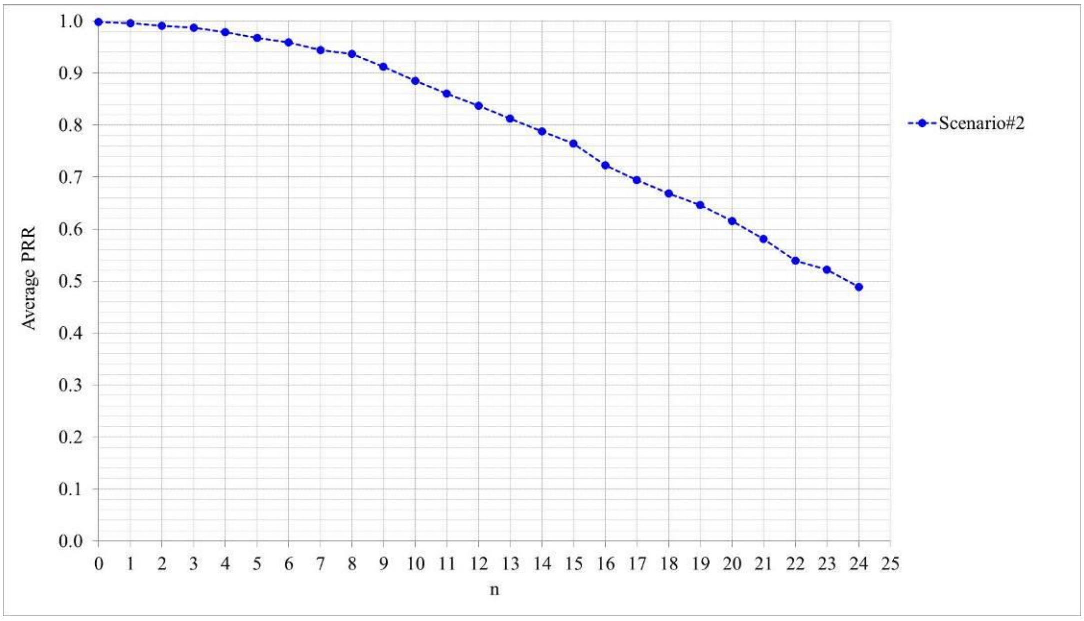
- Source 7



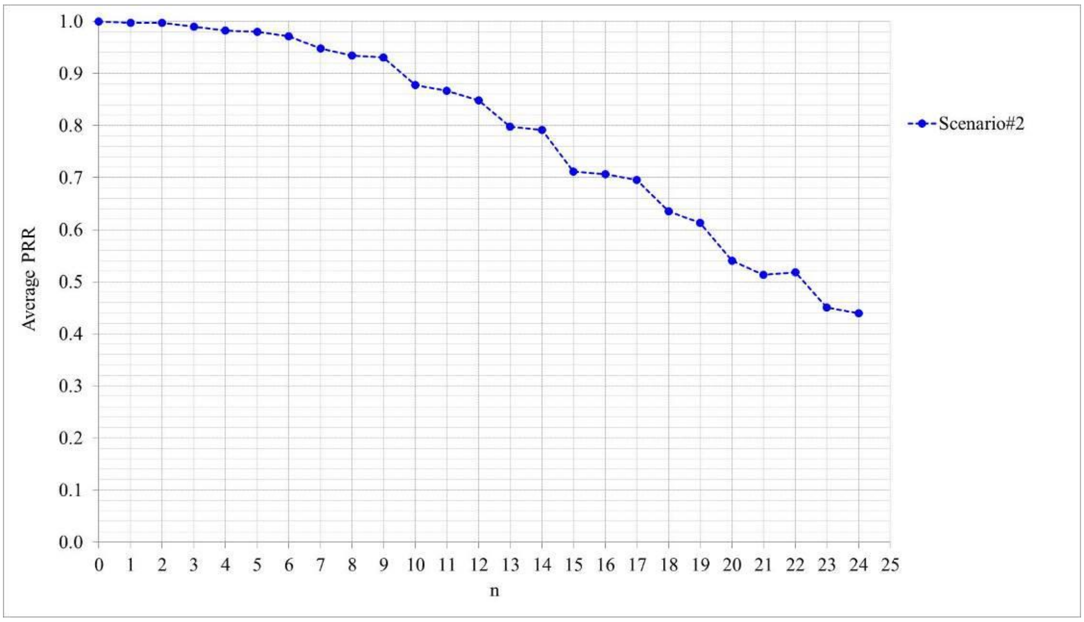
- Source 8



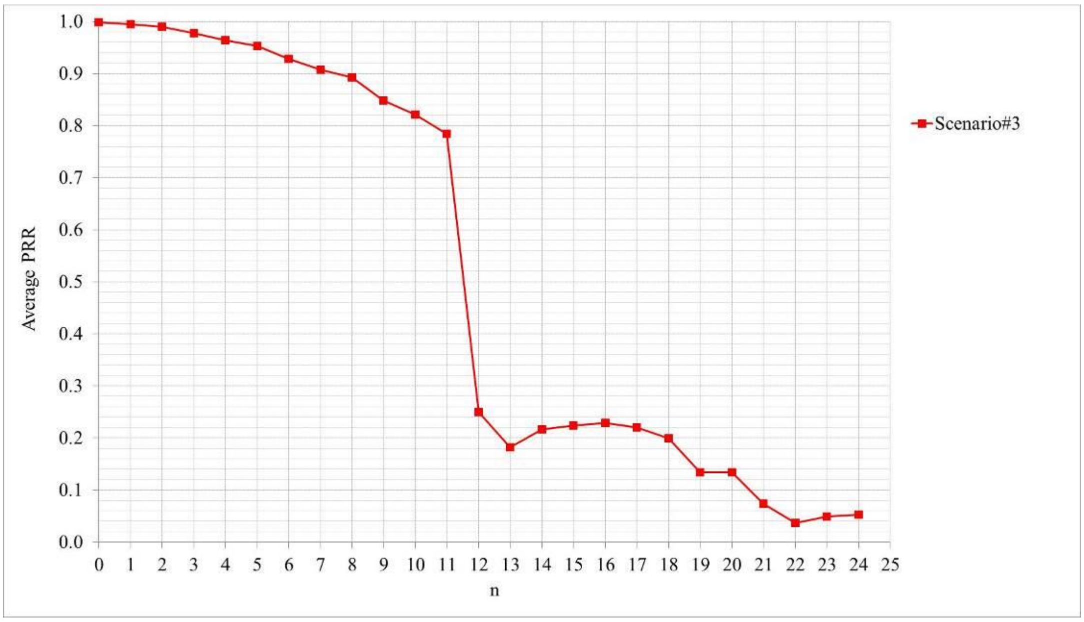
- Source 9



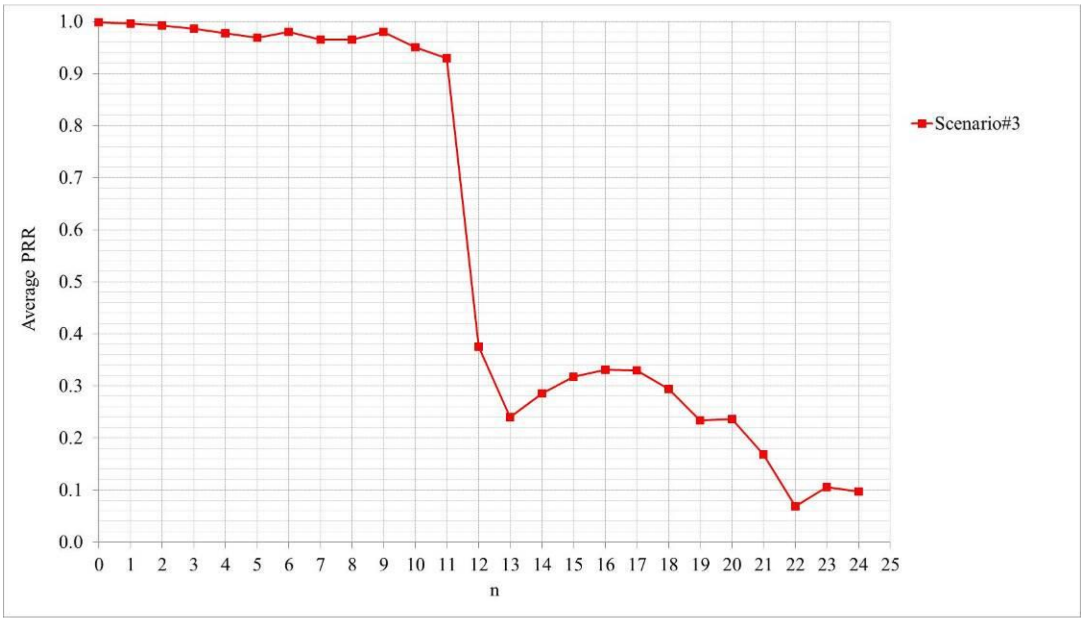
- Source 10



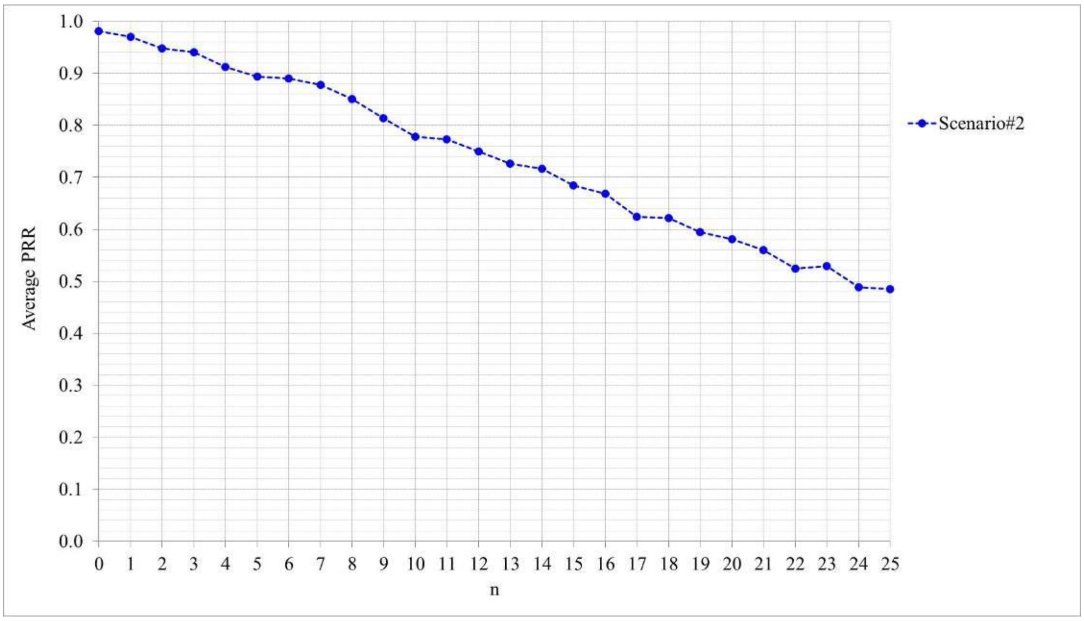
- Source 11



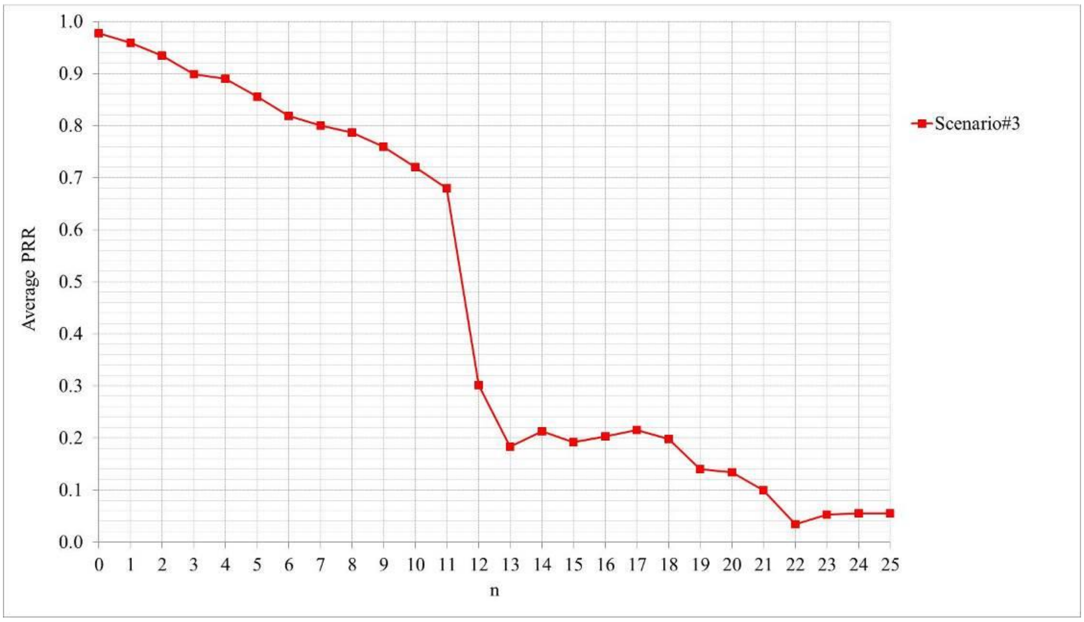
- Source 12



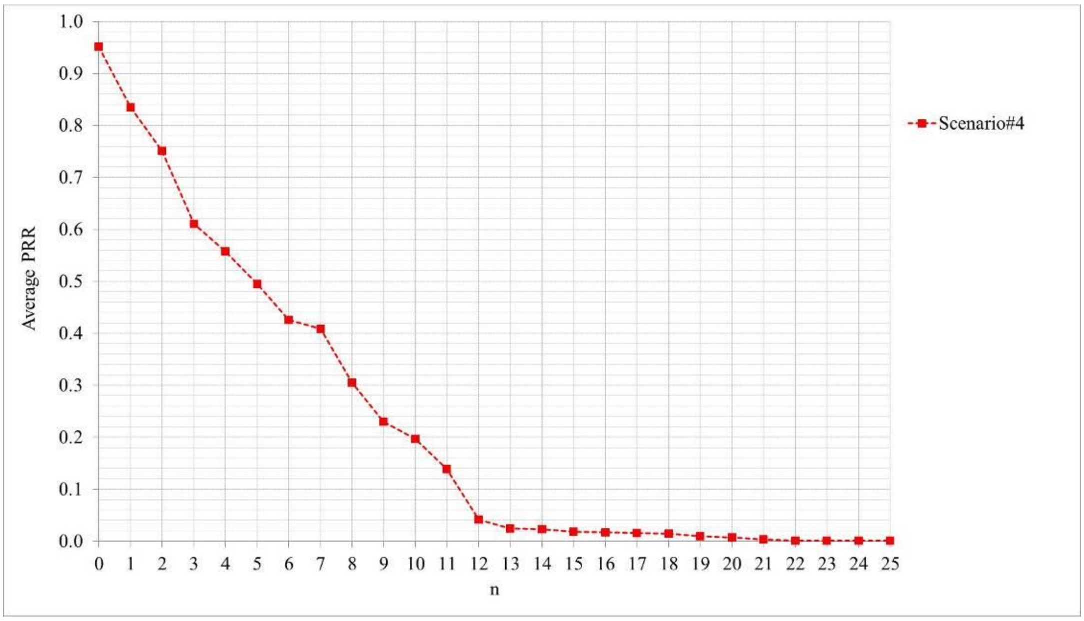
- Source 13



- Source 14



- Source 15



Annex F: Detailed evaluation results for PC5-based V2P

F.1 Simulation assumptions

Description		Source 1	Source 2	Source 3	Source 4	Source 5	Source 6	Source 7
		Scenario#3	**Scenario#3**	**Scenario#4**	**Scenario#3**	**Scenario#3**	**Scenario#3**	**Scenario#3**
Carrier frequency (GHz)		6	6	6	6	6	6	6
Number of carriers		1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)
Number of subframes used to transmit each message	**190 bytes**	3 (1 control + 2 data)	4 (4 control + data)	4 (4 control + data)	2	1 (1 control + 1 data)	1 (1 control + 1 data)	1 (1 control + 1 data)
	300 bytes	4 (1 control + 3 data)	4 (4 control + data)	4 (4 control + data)	4	1 (1 control + 1 data)	1 (1 control + 1 data)	1 (1 control + 1 data)
Number of RBs used to transmit each message in each subframe	**190 bytes**	10 RBs	12 RBs	12 RBs	10	14 PRBs	14 PRBs	14 PRBs
	300 bytes	10 RBs	16 RBs	16 RBs	10	14 PRBs	14 PRBs	14 PRBs
Modulation	**190 bytes**	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK
	300 bytes	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK
Transmission power (in case of non-zero MPR, actual power after applying MPR)		23 dBm	23 dBm	23 dBm	21dBm	23dBm	23dBm	23dBm

Physical channel format (e.g., RS)	4 symbol comb-type DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol comb-type DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol comb DMRS at #2, #5, #8, #11 for both control and data	4 symbol comb DMRS at #2, #5, #8, #11 for both control and data	4 symbol comb DMRS at #2, #5, #8, #11 for both control and data
MPR and inband emission model	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	2 dB ，{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843
Synchronization assumptions	Ideal time synchronization. "1.2KHz' residual frequency offset in every UE-UE link [8]	Ideal time and frequency synchronization.	Ideal time and frequency synchronization.	Ideal time synchronization.	Ideal time and frequency synchronization.	Ideal time and frequency synchronization.	Ideal time and frequency synchronization.
SA assumption (e.g., SA overhead)	Control channel containing 30-bit SA is transmitted in a PRB pair in a subframe before the corresponding data transmissions [24]	The SA and the associated data are transmitted in the same subframe and one SA occupies one PRB.	The SA and the associated data are transmitted in the same subframe and one SA occupies one PRB.	Control channel containing 70-bit SA is transmitted in 2 PRB pair in a subframe of the corresponding data transmissions	The SA and associated data are transmitted in the same subframe; SA and data pool are FDMed, 8 PRB for SA and 42 PRB for data in Freq. domain	The SA and associated data are transmitted in the same subframe; SA and data pool are FDMed, 8 PRB for SA and 42 PRB for data in Freq. domain	The SA and associated data are transmitted in the same subframe; SA and data pool are FDMed, 8 PRB for SA and 42 PRB for data in Freq. domain
Resource allocation principle	- SA pool is TDMed with data pool [24] - Vehicle UE: 'SA decoding with energy measurement based sensing' and 'Location based resource partitioning' [25] - Pedestrian UE: 'SA decoding with energy measurement based sensing' and 'Location based resource partitioning' [25]	Random	Random	"Enhanced sensing based semi-persistent resource occupy" for V-UE: - UE sensing available resource via SA decoding and energy measurement. - Each SA indicates the data transmission resource in current TTI, and upcoming N transmission(s) resource, where the indicated N transmissions resource can be used a different TB. - Reselection duration prefer 1	Pedestrain UE: Partial sensing - 10 ms sensing duration every 1 second (details as described in [26], [27]); Vehicel UE: Sensing based resource selection - energy sensing, and the resource with least receiving energy is selected (details in [26])	Pedestain UE: Random Vehicel UE: Sensing based resource selection - energy sensing, and the resource with least receiving energy is selected (details in [26])	Pedestrain UE: no Tx Vehicle UE: Sensing based resource selection - energy sensing, and the resource with least receiving energy is selected; Assuming UE enters NW one by one.

				transmission period (100ms). - See more detail in [23]. "Random selection mechanism" for P-UE.			
Remark (e.g., latency requirement for P2V when another value of latency requirement larger than 100ms (e.g., 1000ms) is assumed in the evaluation, number of road grids assumed in the evaluation, etc)	- 14 road grids (Figure A.1.3-1 in TR36.885) are assumed	14 road grids in (4), P-UE does not transmit	14 road grids in (4), P-UE does not transmit	V-UE and P-UE share the same carrier and use orthogonal resource pools, which is TDMed with 1 subframe for P2V and the other 9 subframes for V2V in each 10ms.	- 14 road grids (Figure A.1.3-1 in TR36.885) are assumed - Shared resource pool for V2V and V2P	- 14 road grids (Figure A.1.3-1 in TR36.885) are assumed - Shared resource pool for V2V and V2P	- 14 road grids (Figure A.1.3-1 in TR36.885) are assumed

Description		**Source 8**	**Source 9**	**Source 10**	**Source 11**	**Source 12**	**Source 13**	**Source 14**
		Scenario#4	**Scenario#4**	**Scenario#4**	**Scenario#3**	**Scenario#4**	**Scenario#3**	**Scenario#3**
Carrier frequency (GHz)		6	6	6	6	6	6	6
Number of carriers		1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)	1 (10 MHz)
Number of subframes used to transmit each message	**190 bytes**	1 (1 control + 1 data)	1 (1 control + 1 data)	1 (1 control + 1 data)	1 (1 control + data)	1 (1 control + data)	2 (2 control + 2 data)	1
	300 bytes	1 (1 control + 1 data)	1 (1 control + 1 data)	1 (1 control + 1 data)	1 (1 control + data)	1 (1 control + data)	2 (2 control + 2 data)	1
Number of RBs used to transmit each message	**190 bytes**	14 PRBs	14 PRBs	14 PRBs	14 RBs	14 RBs	10 RBs	16RBs

in each subframe	**300 bytes**	14 PRBs	14 PRBs	14 PRBs	20 RBs	20 RBs	15 RBs	25RBs
Modulation	**190 bytes**	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK
	300 bytes	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK
Transmission power (in case of non-zero MPR, actual power after applying MPR)		23dBm	23dBm	23dBm	22 dBm	22 dBm	23 dBm	23dBm
Physical channel format (e.g., RS)		4 symbol comb DMRS at #2, #5, #8, #11 for both control and data	4 symbol comb DMRS at #2, #5, #8, #11 for both control and data	4 symbol comb DMRS at #2, #5, #8, #11 for both control and data	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data
MPR and inband emission model		'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	'{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843
Synchronization assumptions		Ideal time and frequency synchronization.	Ideal time and frequency synchronization.	Ideal time and frequency synchronization.	Ideal time synchronization. Each UE has a frequency offset uniformly distributed in [-600 600] Hz	Ideal time synchronization. Each UE has a frequency offset uniformly distributed in [-600 600] Hz	Ideal time and frequency synchronization.	Ideal time synchronization and frequency offset
SA assumption (e.g., SA overhead)		The SA and associated data are transmitted in the same subframe; SA and data pool are FDMed, 8 PRB for SA and 42 PRB for data in Freq. domain	The SA and associated data are transmitted in the same subframe; SA and data pool are FDMed, 8 PRB for SA and 42 PRB for data in Freq. domain	The SA and associated data are transmitted in the same subframe; SA and data pool are FDMed, 8 PRB for SA and 42 PRB for data in Freq. domain	The SA and the associated data are transmitted in the same subframe and one SA occupies one PRB. The SA contains 64 bits including CRC.	The SA and the associated data are transmitted in the same subframe and one SA occupies one PRB. The SA contains 64 bits including CRC.	The SA and the associated data are transmitted in the same subframe and one SA occupies one PRB.	The SA and the associated data are transmitted in the same subframe.SA and data pool are FDMed, 6 PRB for SA and 44 PRB for data in Freq. one SA occupies one PRB.

Resource allocation principle	pedestrian UE: Partial sensing - 10 ms sensing duration every 1 second (details as described in [26], [27]); Vehicle UE: Sensing based resource selection - energy sensing, and the resource with least receiving energy is selected (details in [26])	Pedestrian UE: Random Vehicel UE: Sensing based resource selection - energy sensing, and the resource with least receiving energy is selected (details in [26])	Pedestrian UE: no Tx Vehicle UE: Sensing based resource selection - energy sensing, and the resource with least receiving energy is selected; Assuming UE enters NW one by one.	Vehicle UEs uses sensing-based resource selection Pedestrian UEs uses random resource selection. All UEs share the same SA/DATA pool.	Vehicle UEs uses sensing-based resource selection Pedestrian UEs uses random resource selection. All UEs share the same SA/DATA pool.	Random	Random resource selection
Remark (e.g., latency requirement for P2V when another value of latency requirement larger than 100ms (e.g., 1000ms) is assumed in the evaluation, number of road grids assumed in the evaluation, etc)	- 14 road grids (Figure A.1.3-1 in TR36.885) are assumed - Shared resource pool for V2V and V2P	- 14 road grids (Figure A.1.3-1 in TR36.885) are assumed - Shared resource pool for V2V and V2P	- 14 road grids (Figure A.1.3-1 in TR36.885) are assumed			9 road grids (Figure A.1.2-1 in TR36.885) are assumed	V2P/P2V and V2V share the same resource pool

Description		**Source 15**	**Source 16**	**Source 17**
		Scenario#3	**Scenario#4**	**Scenario#4**
Carrier frequency (GHz)		6	6	6
Number of carriers		1 (10 MHz)	1 (10 MHz)	1 (10 MHz)
Number of subframes used to transmit each message	**190 bytes**	1	1	1
	300 bytes	1	1	1
Number of RBs used to transmit each message	**190 bytes**	16RBs	16RBs	16RBs

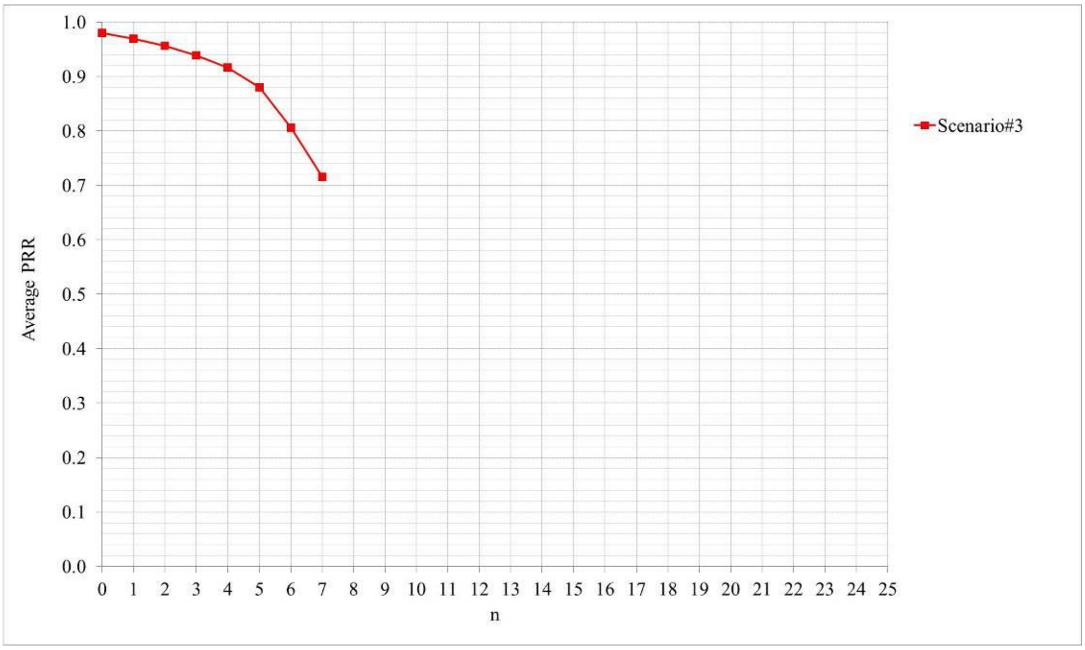
in each subframe	**300 bytes**	25RBs	25RBs	25RBs
Modulation	**190 bytes**	QPSK	QPSK	QPSK
	300 bytes	QPSK	QPSK	QPSK
Transmission power (in case of non-zero MPR, actual power after applying MPR)		23dBm	23dBm	23dBm
Physical channel format (e.g., RS)		4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data	4 symbol PUSCH DMRS positioned at #2, #5, #8, #11 for both of control and data
MPR and inband emission model		{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843	{W, X, Y, Z} = {3, 6, 3, 3}' as in TR 36.843
Synchronization assumptions		Ideal time synchronization and frequency offset	Ideal time synchronization and frequency offset	Ideal time synchronization and frequency offset
SA assumption (e.g., SA overhead)		The SA and the associated data are transmitted in the same subframe.SA and data pool are FDMed, 6 PRB for SA and 44 PRB for data in Freq. one SA occupies one PRB.	The SA and the associated data are transmitted in the same subframe.SA and data pool are FDMed, 6 PRB for SA and 44 PRB for data in Freq. one SA occupies one PRB.	The SA and the associated data are transmitted in the same subframe.SA and data pool are FDMed, 6 PRB for SA and 44 PRB for data in Freq. one SA occupies one PRB.
Resource allocation principle		Random resource selection	Random resource selection	Random resource selection

Remark (e.g., latency requirement for P2V when another value of latency requirement larger than 100ms (e.g., 1000ms) is assumed in the evaluation, number of road grids assumed in the evaluation, etc)	V2P/P2V and V2V use orthogonal resource pools.one subframe is for P2V per 10 subframes	V2P/P2V and V2V share the same resource pool	V2P/P2V and V2V use orthogonal resource pools.one subframe is for P2V per 10 subframes

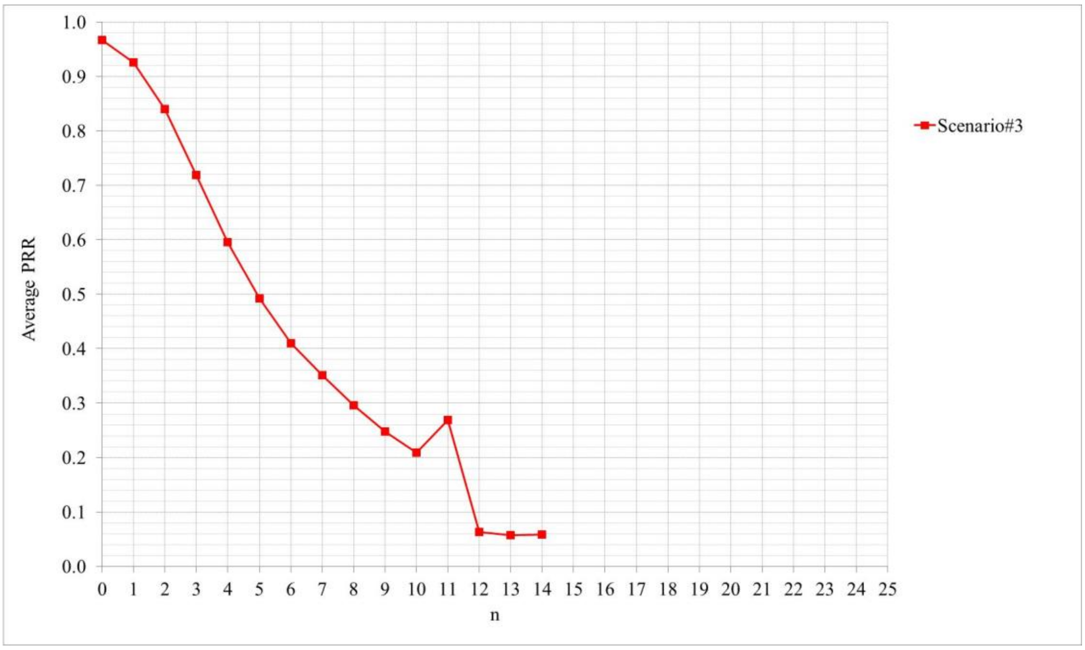
F.2 Simulation results

Average PRR of each source is as follows (a=n*20 m, b=(n+1)*20 m):

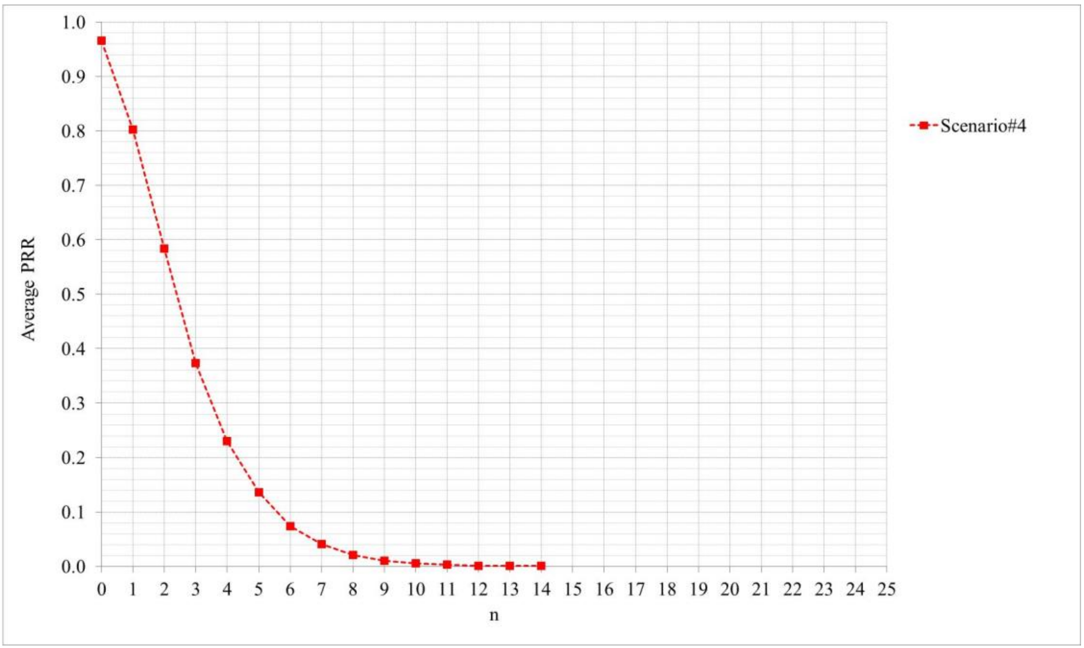
- V-UE RX of V-UE TX without P-UE TX
    - Source 1



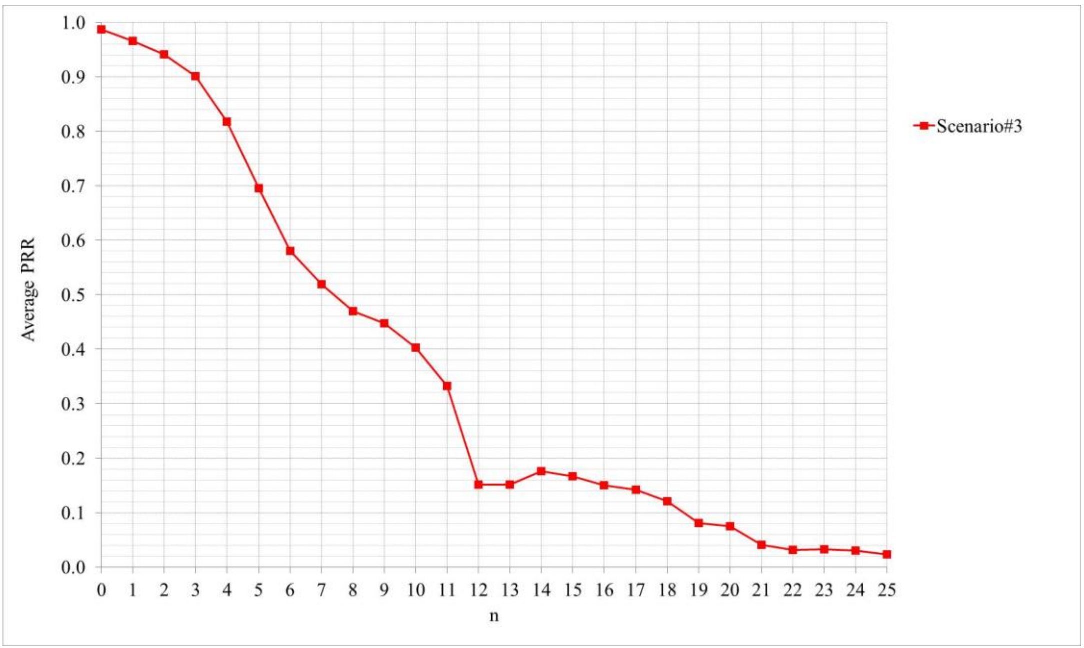
    - Source 2



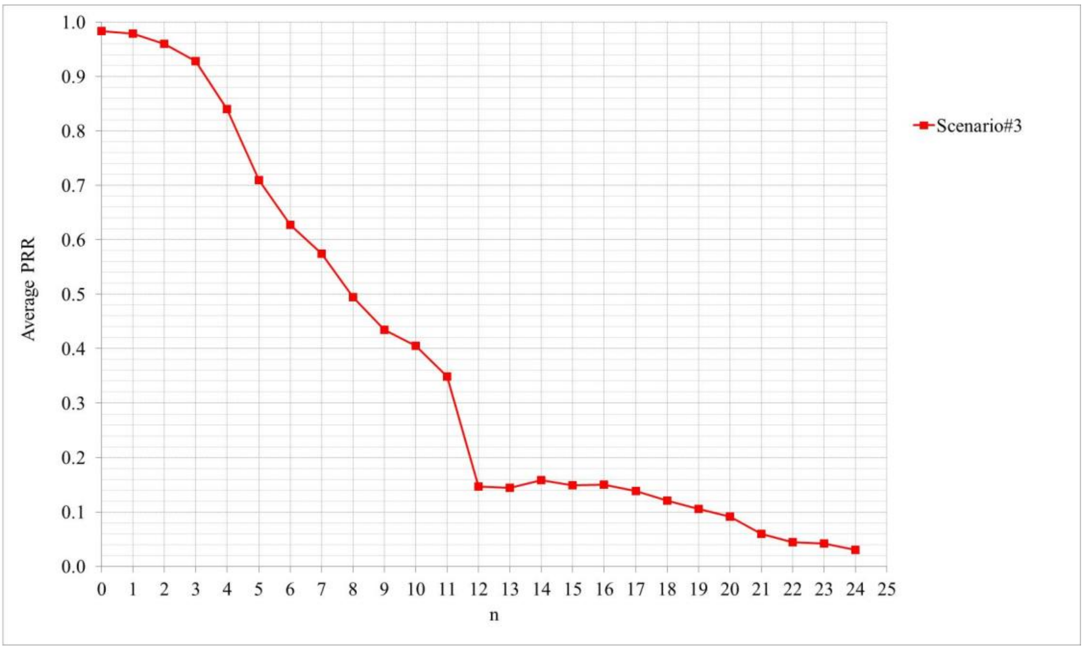
    - Source 3



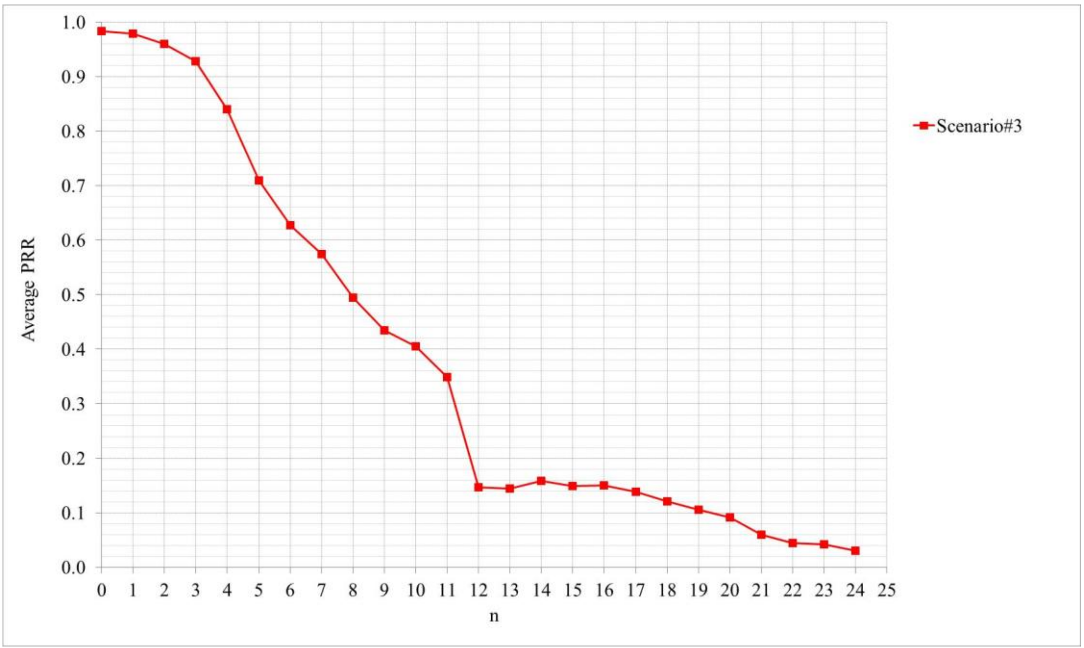
- Source 4



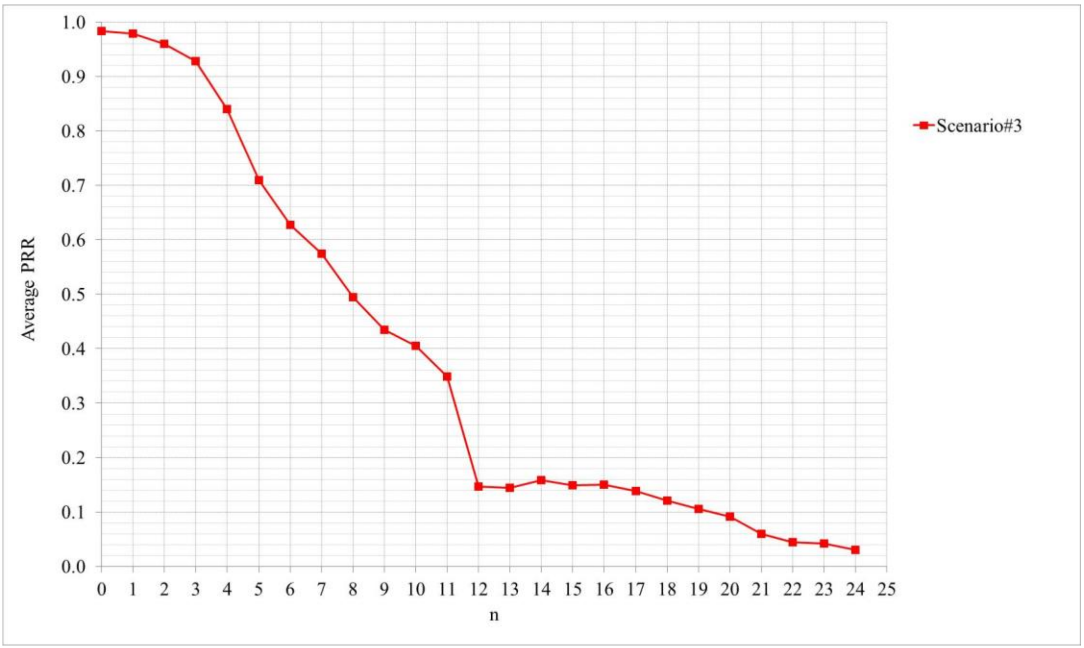
- Source 5



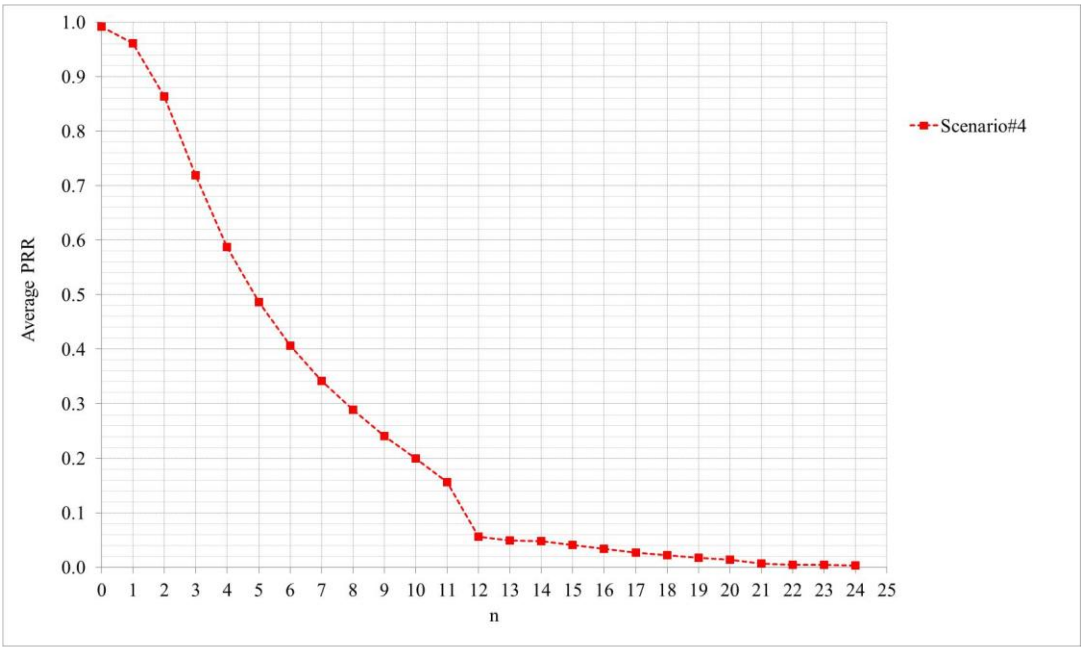
- Source 6



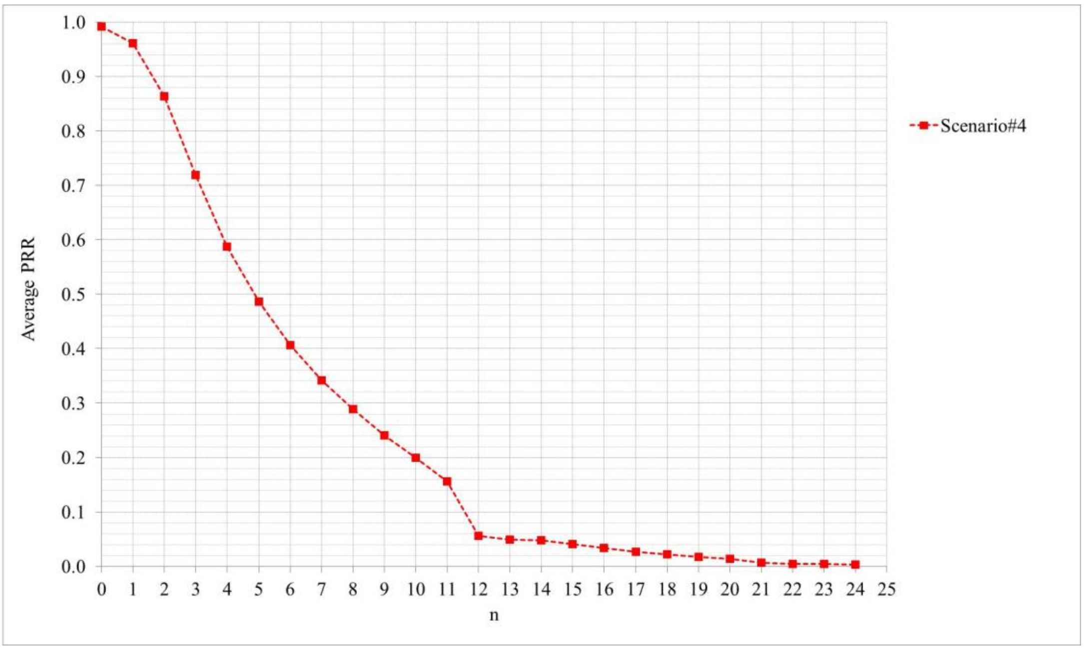
- Source 7



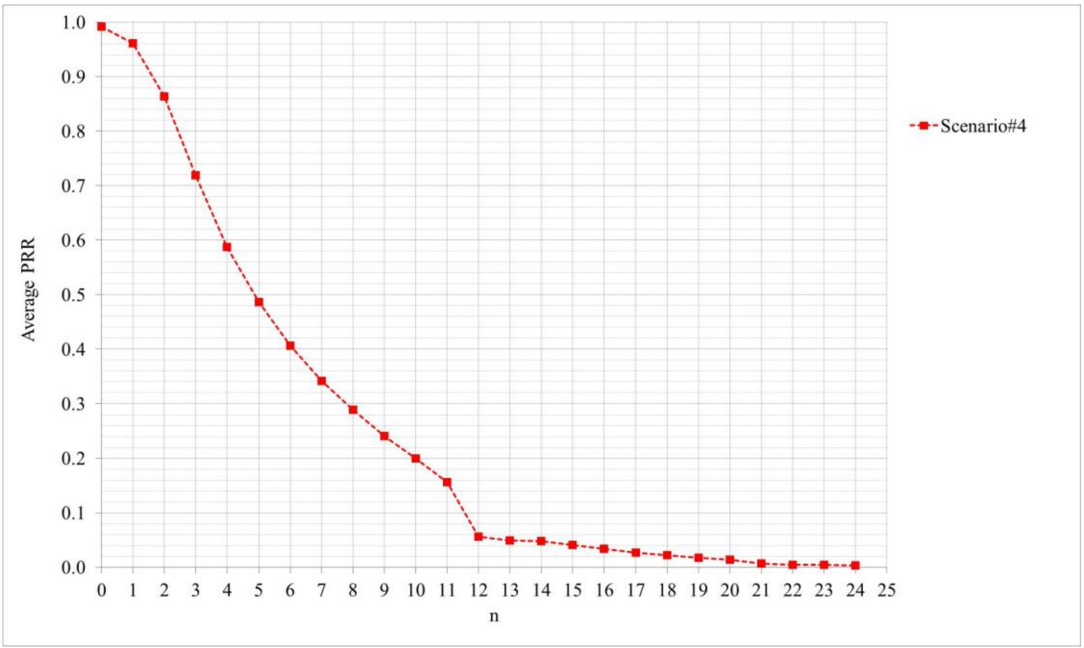
- Source 8



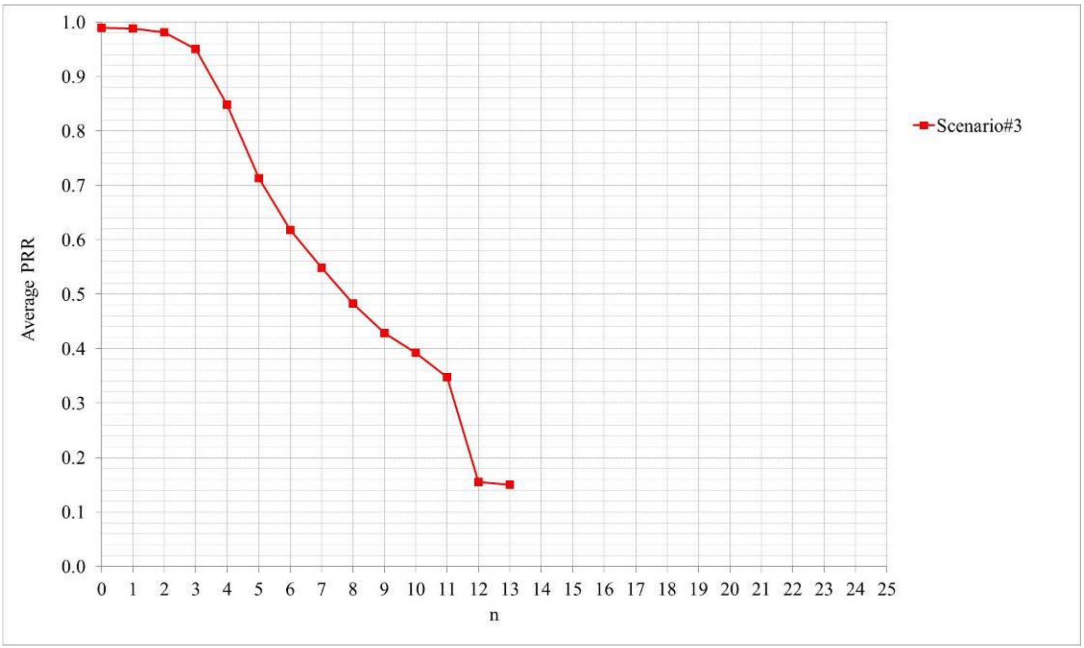
- Source 9



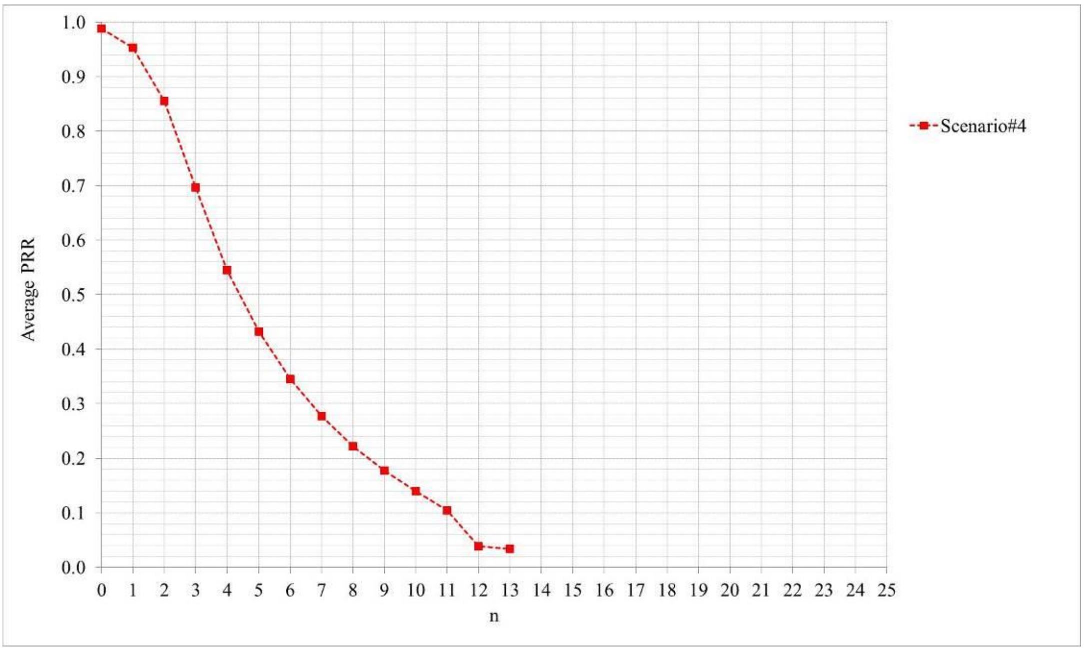
- Source 10



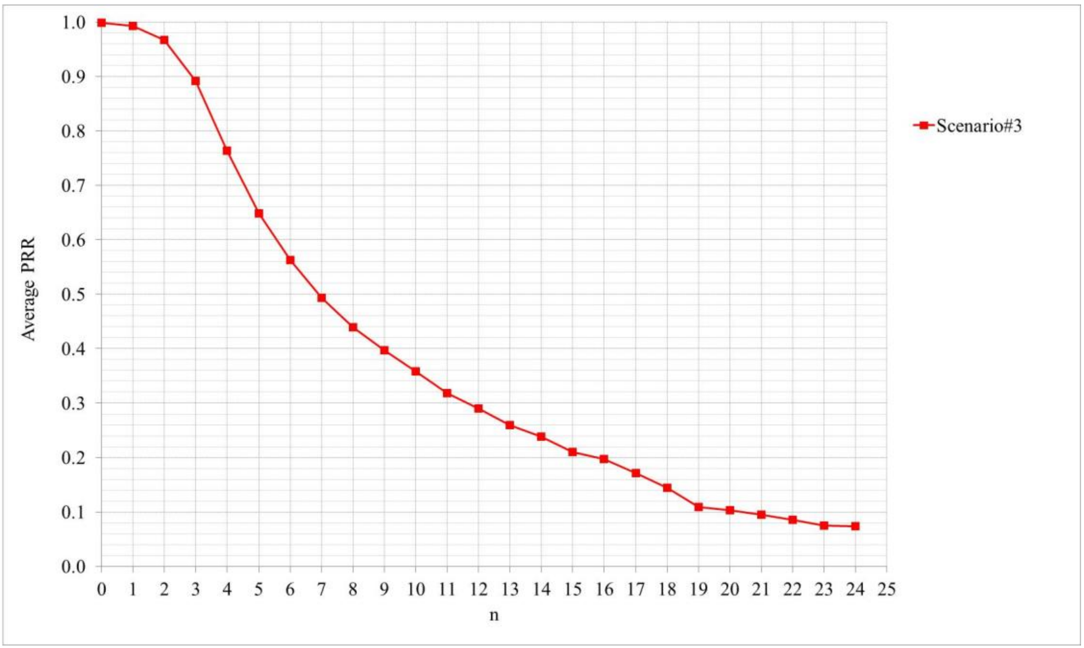
- Source 11



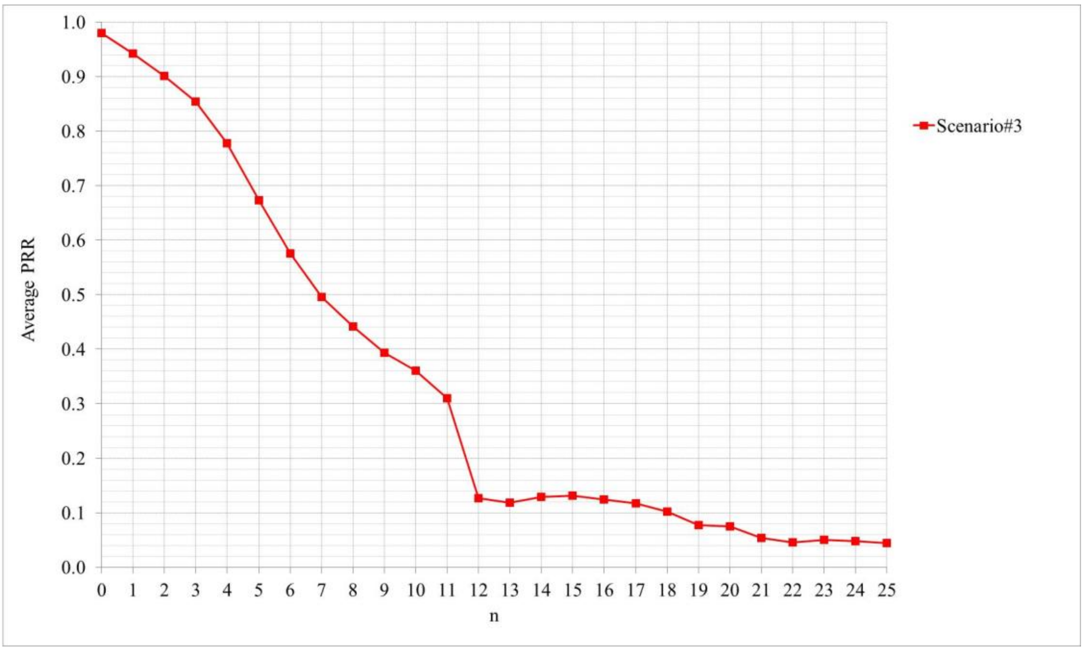
- Source 12



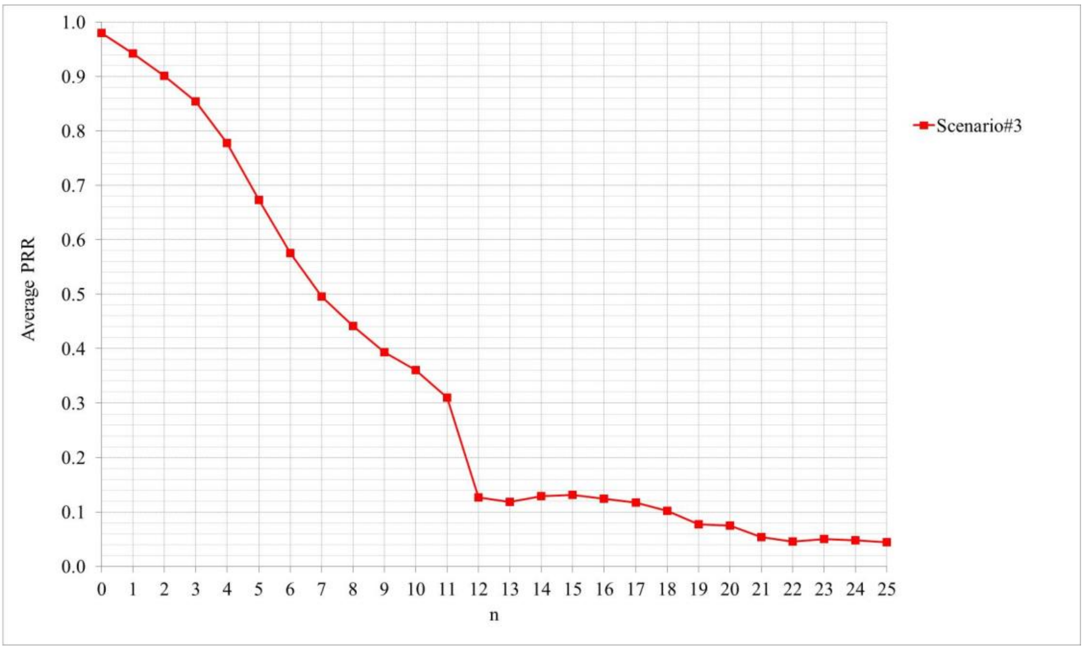
- Source 13



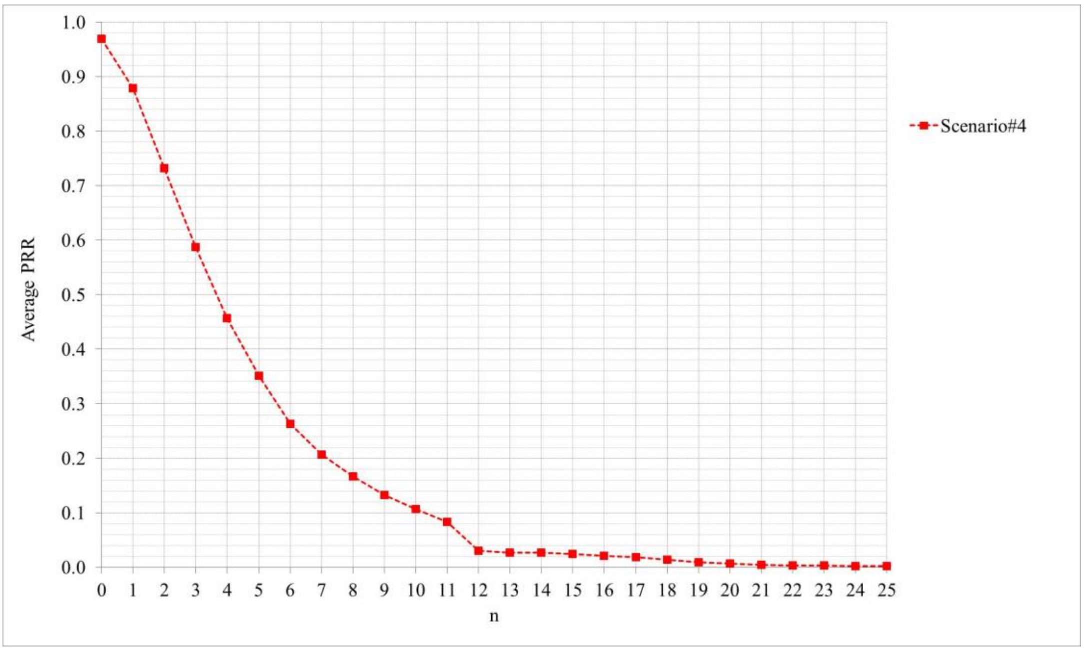
- Source 14



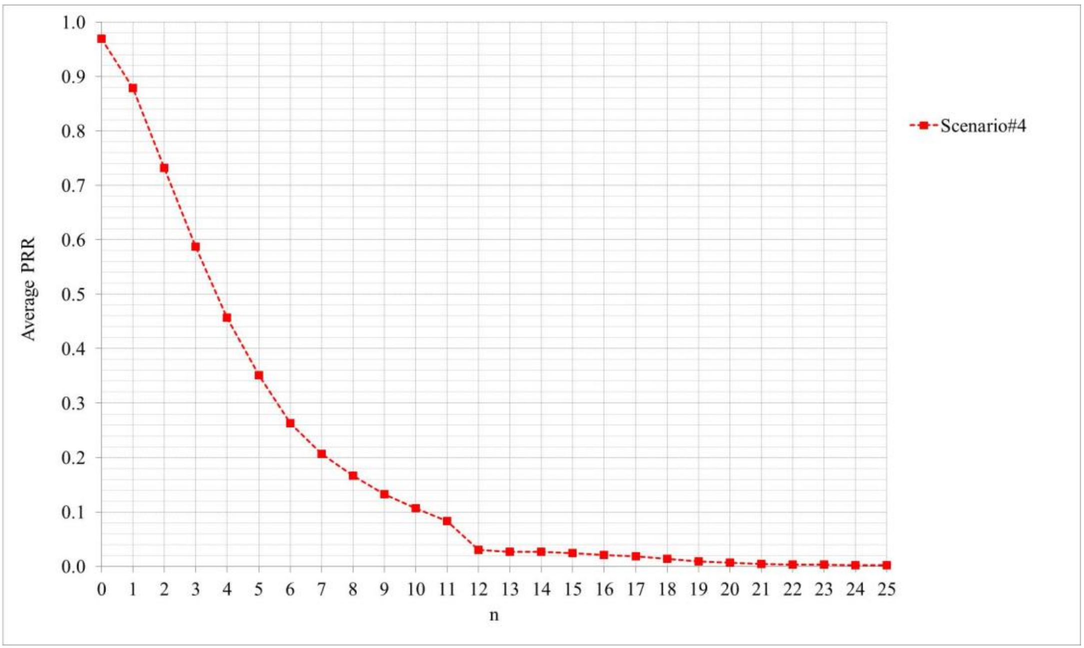
- Source 15



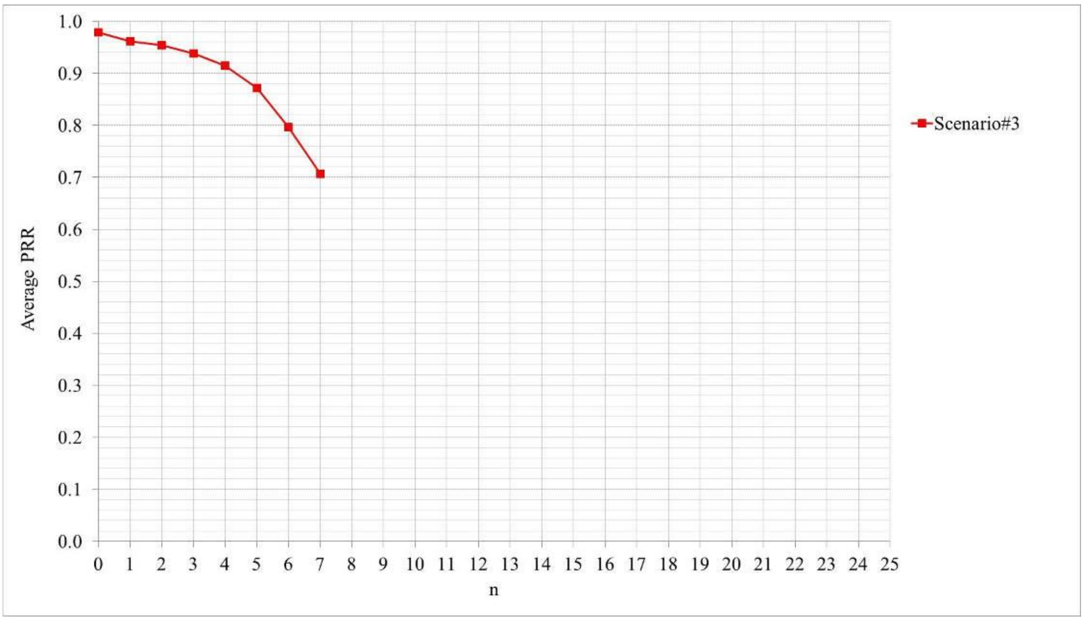
- Source 16



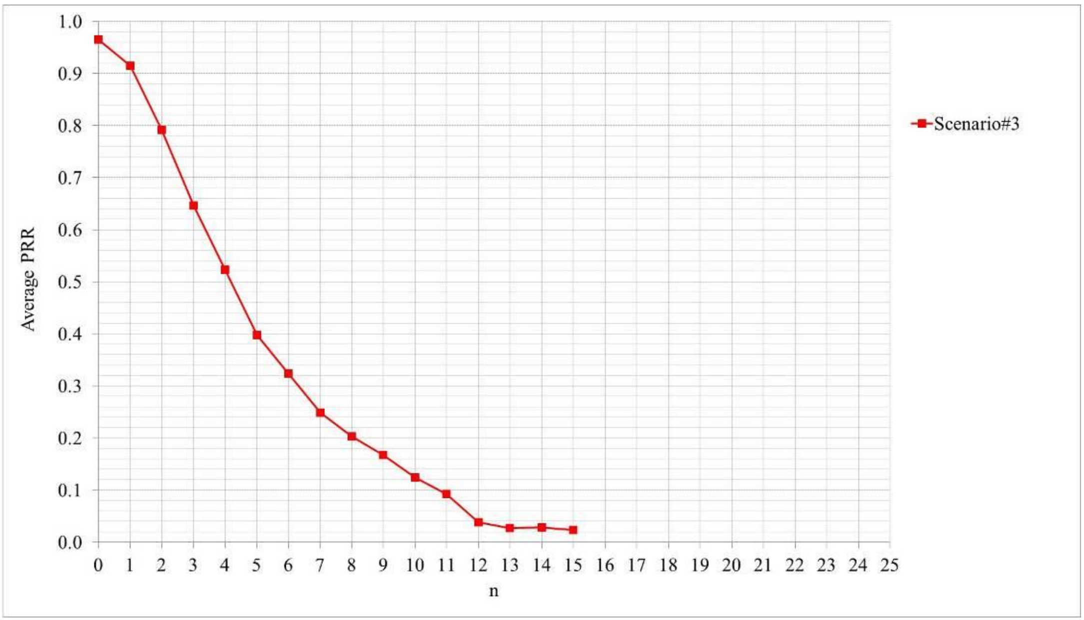
- Source 17



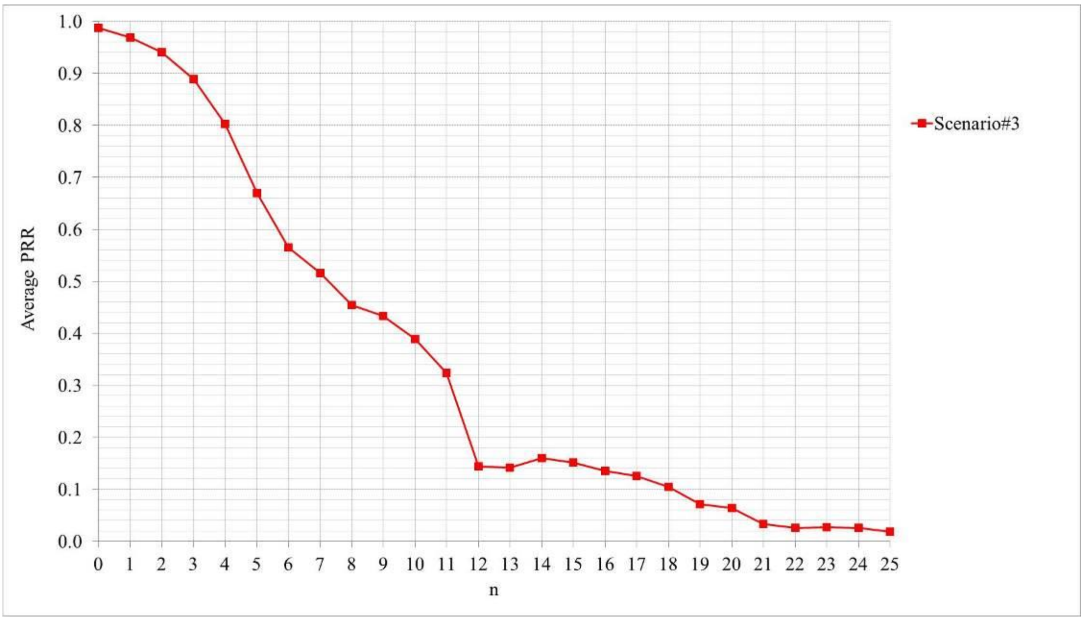
- V-UE RX of V-UE TX with P-UE TX
    - Source 1



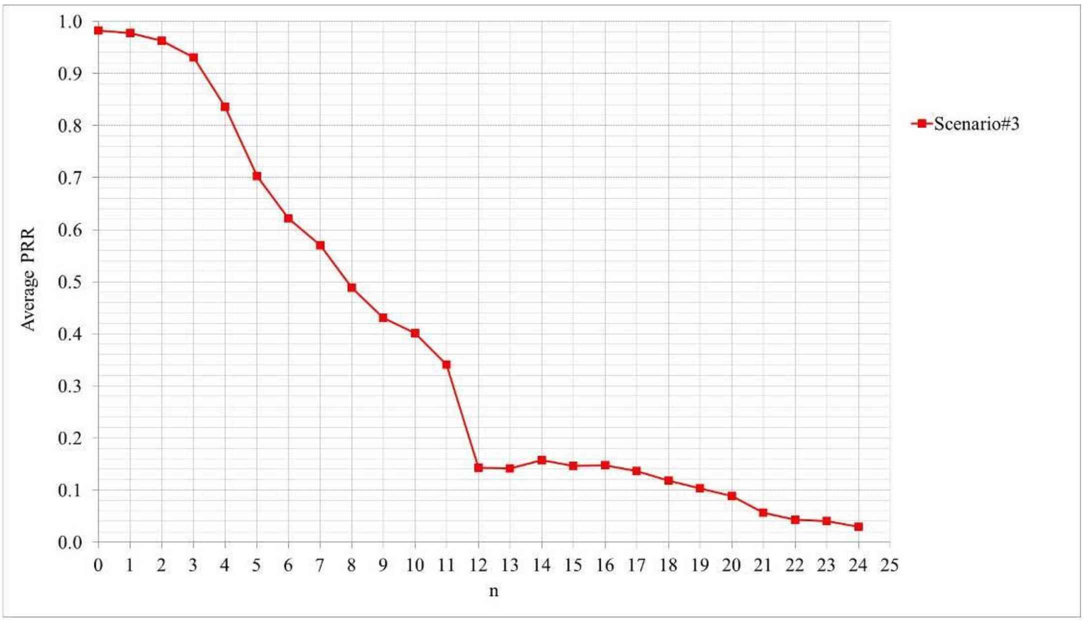
    - Source 2



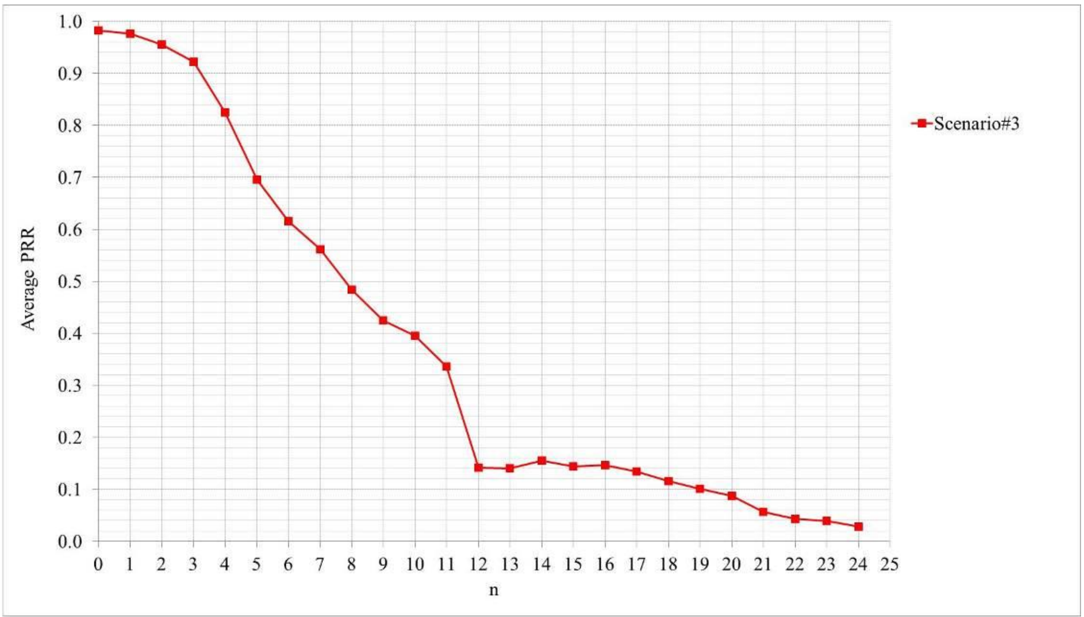
- Source 4



- Source 5



- Source 6



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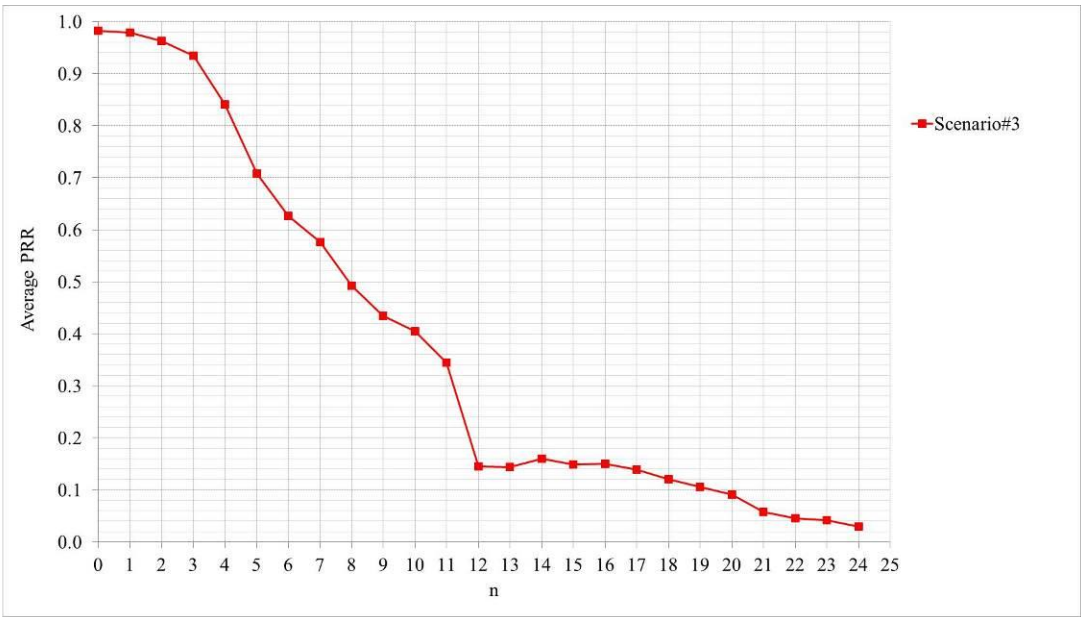
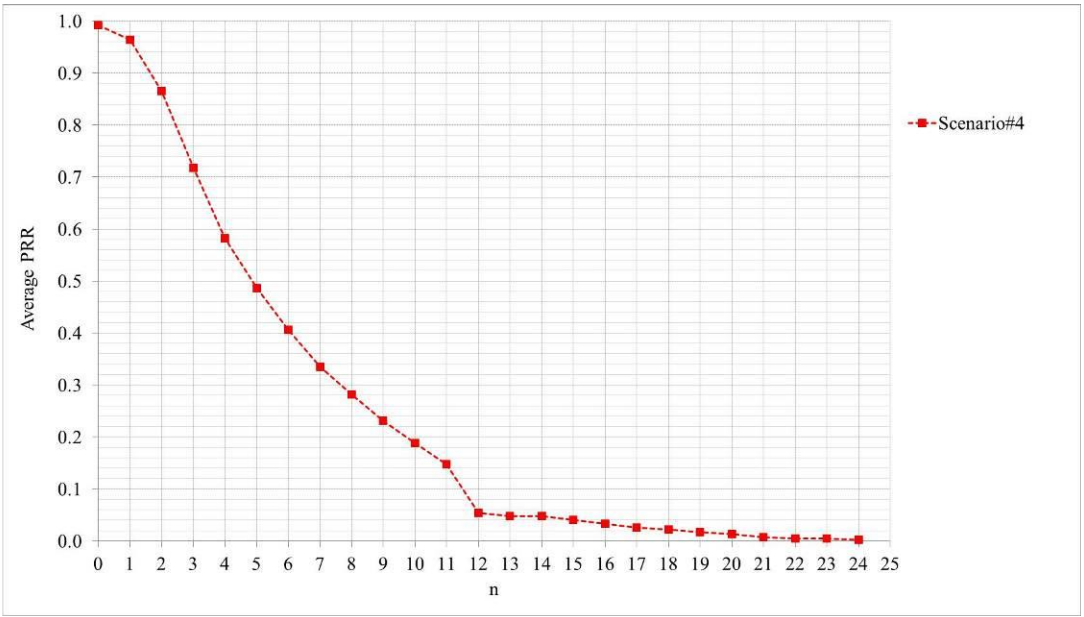


- Source 8



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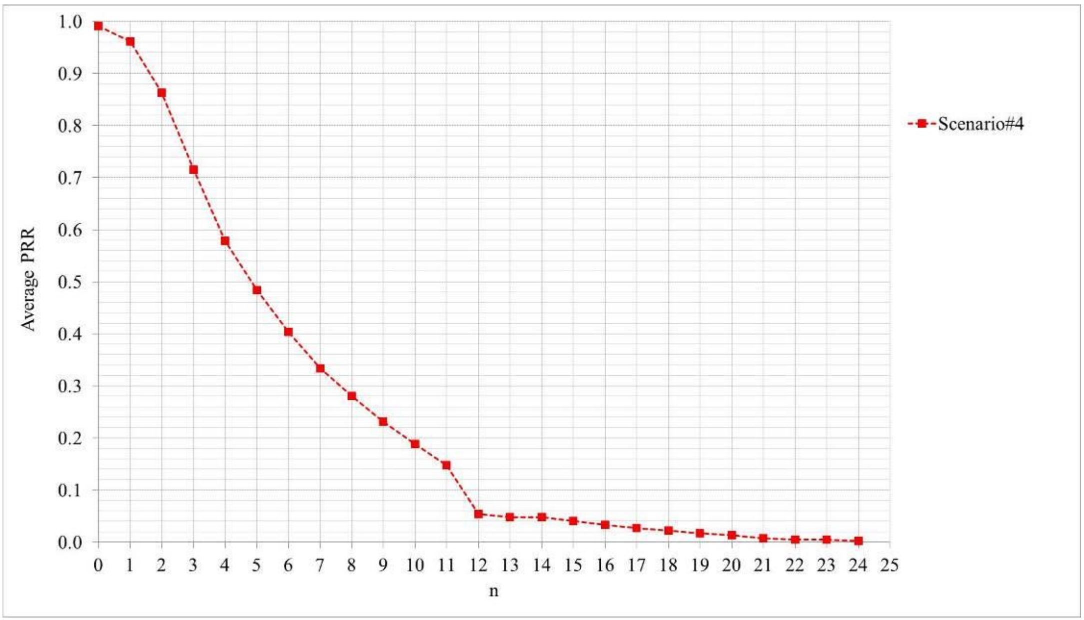

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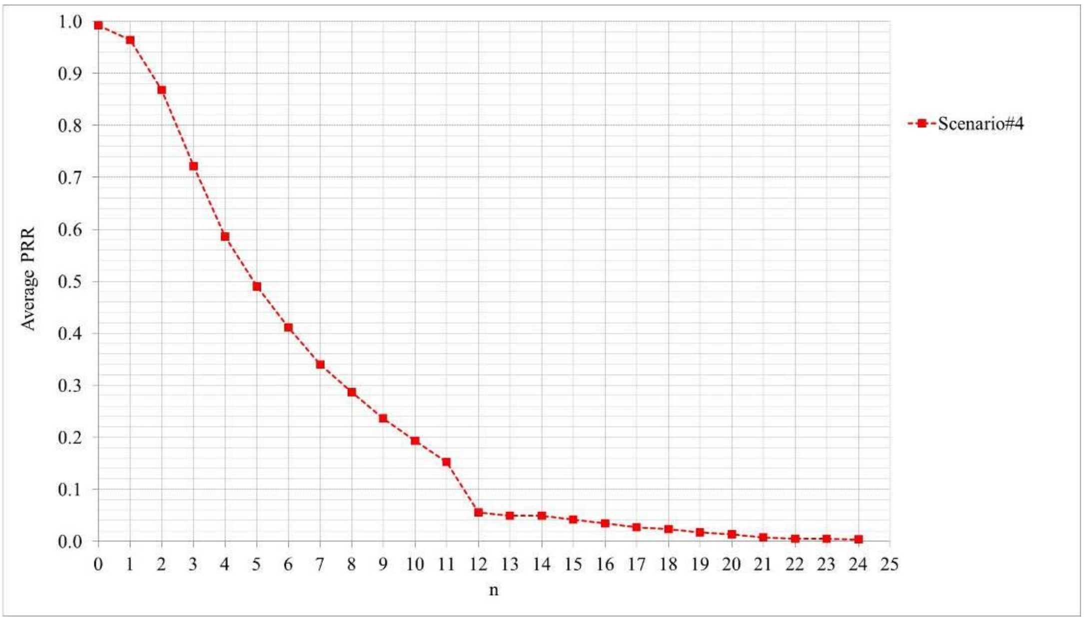
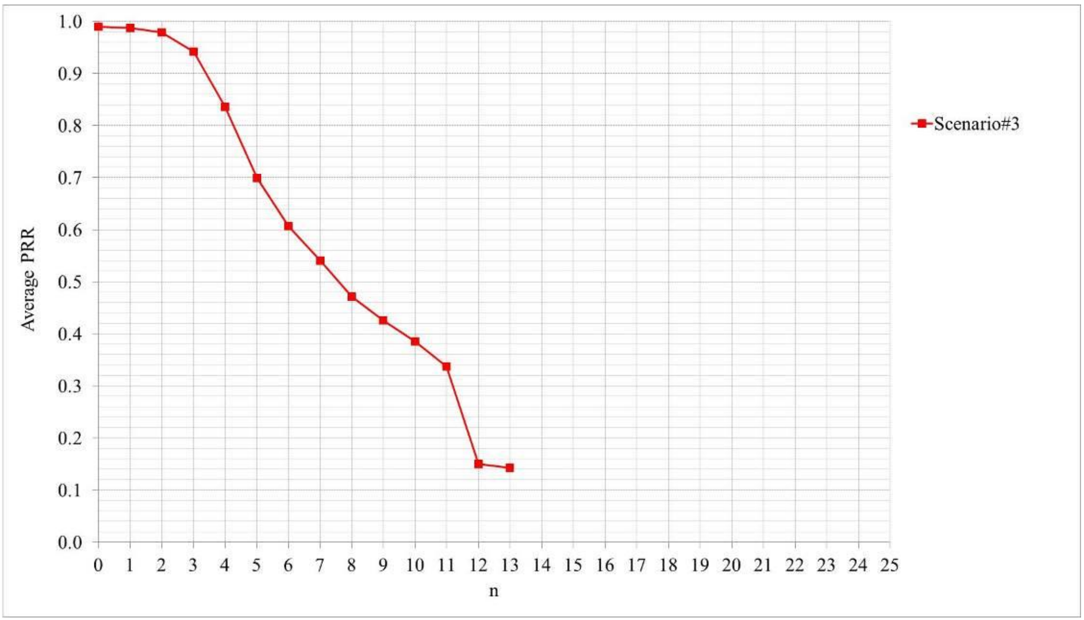


- Source 11



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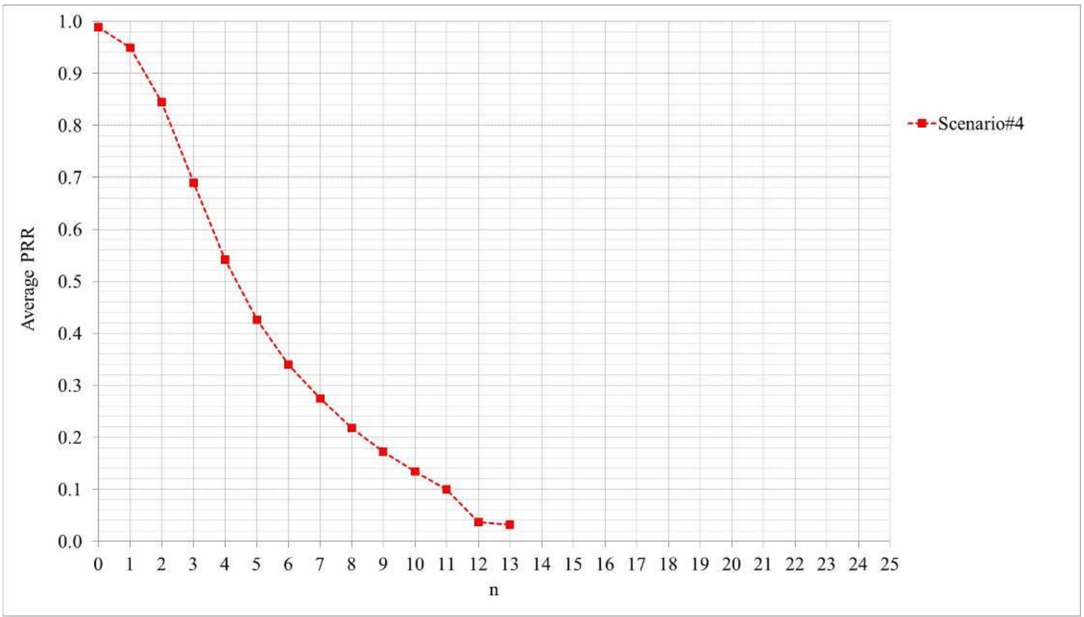
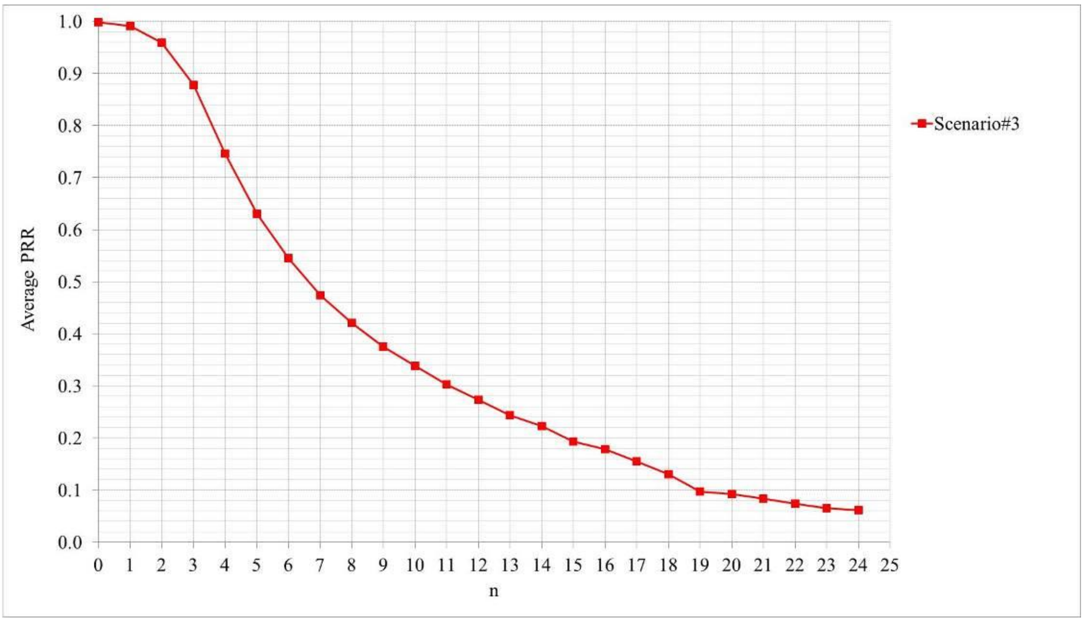
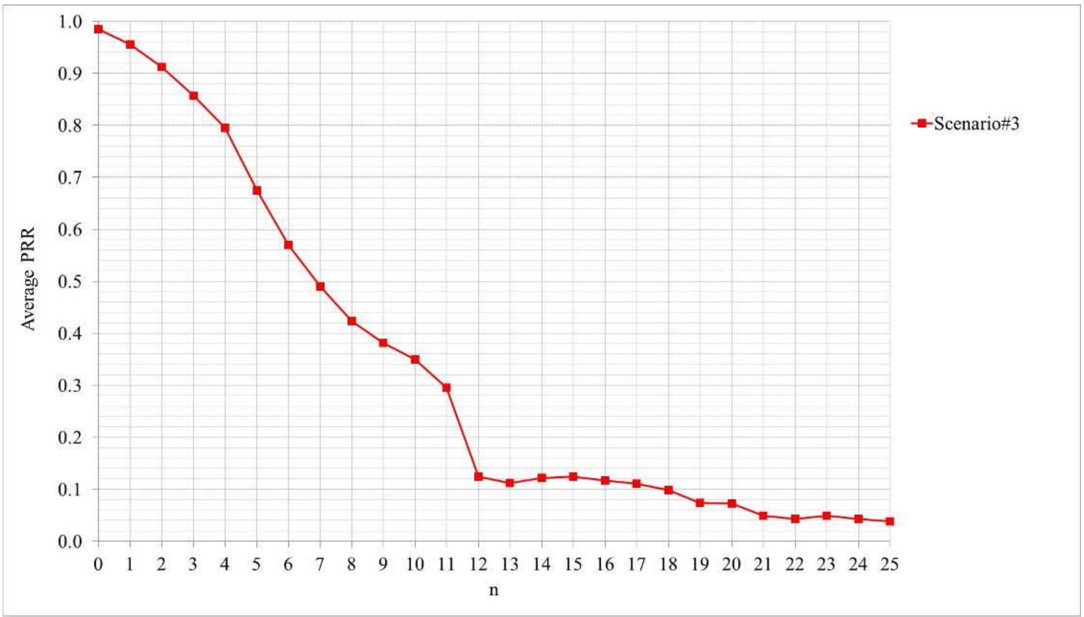


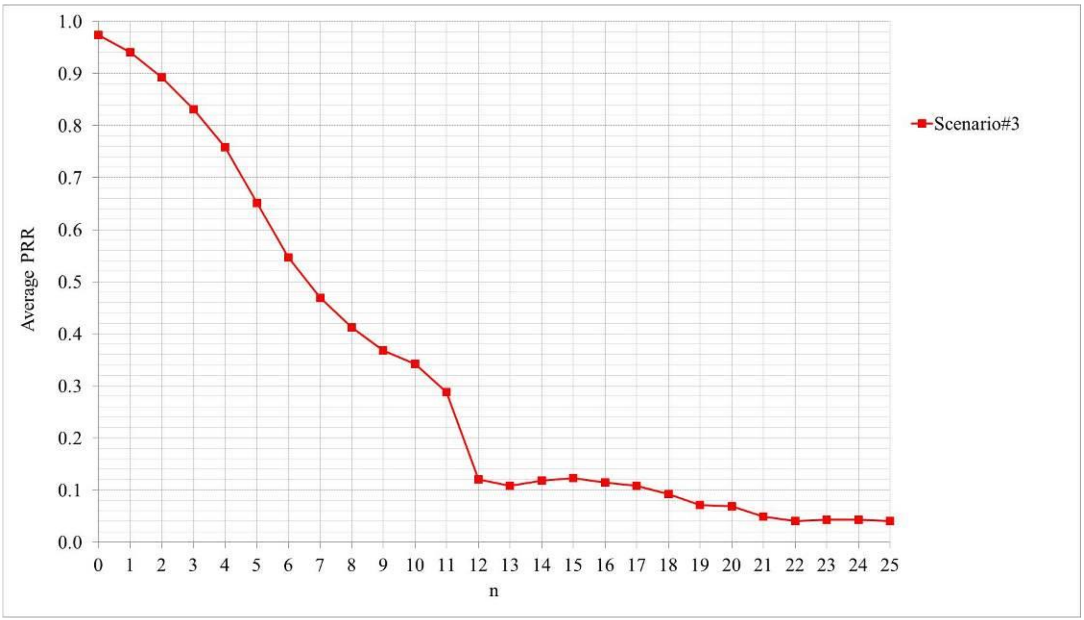
- Source 13



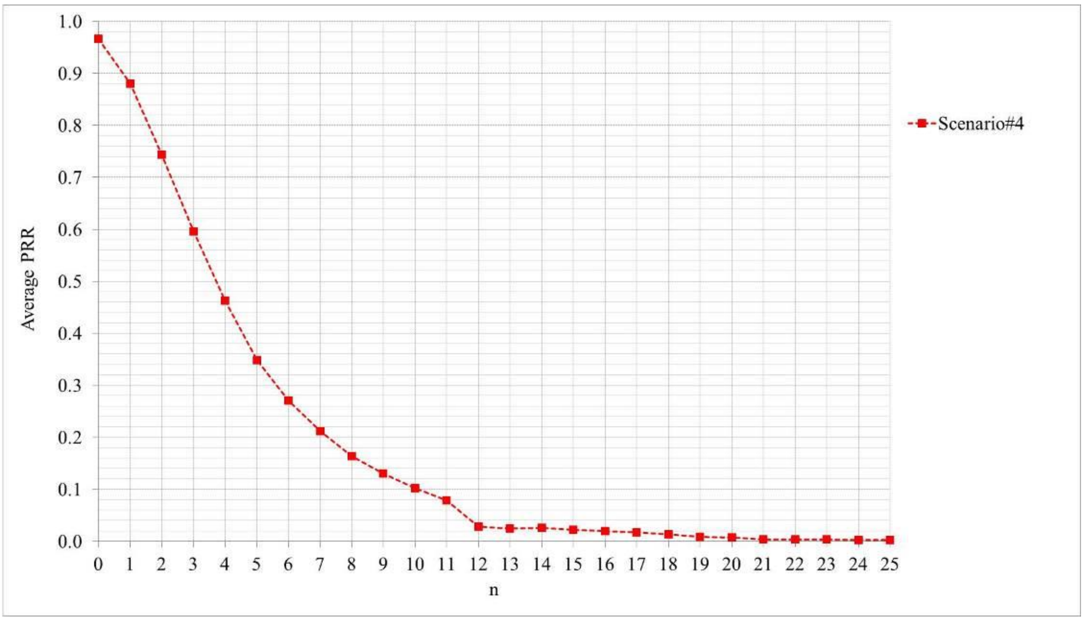
- Source 14



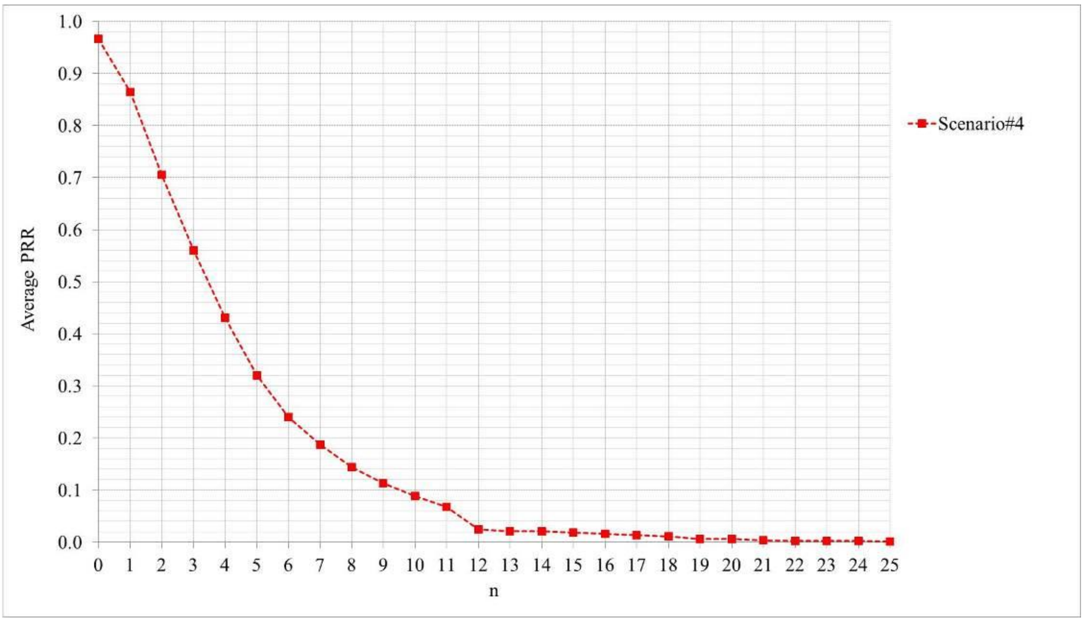
- Source 15



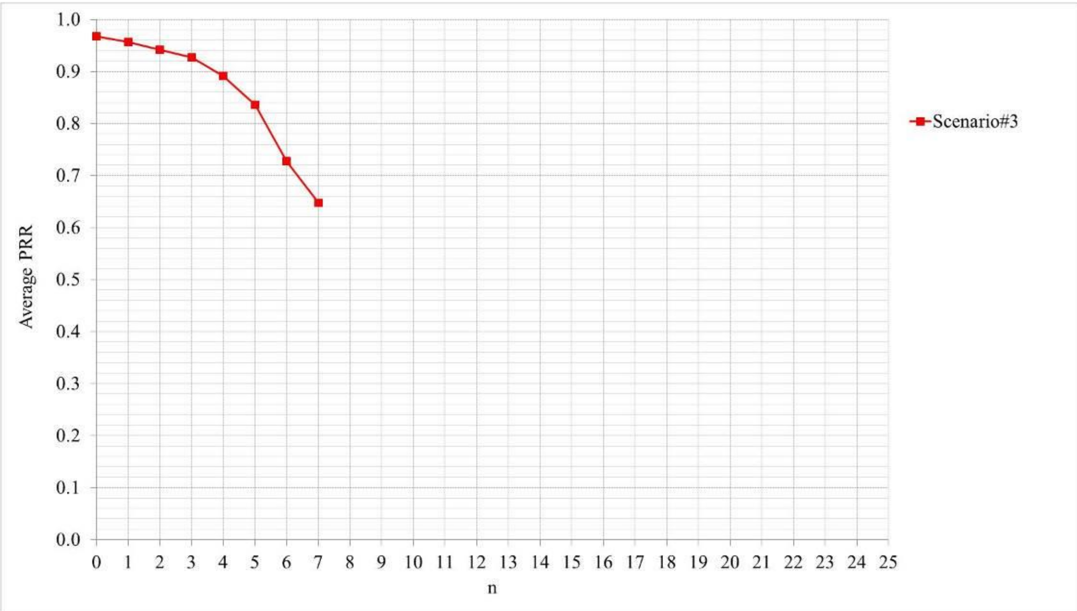
- Source 16



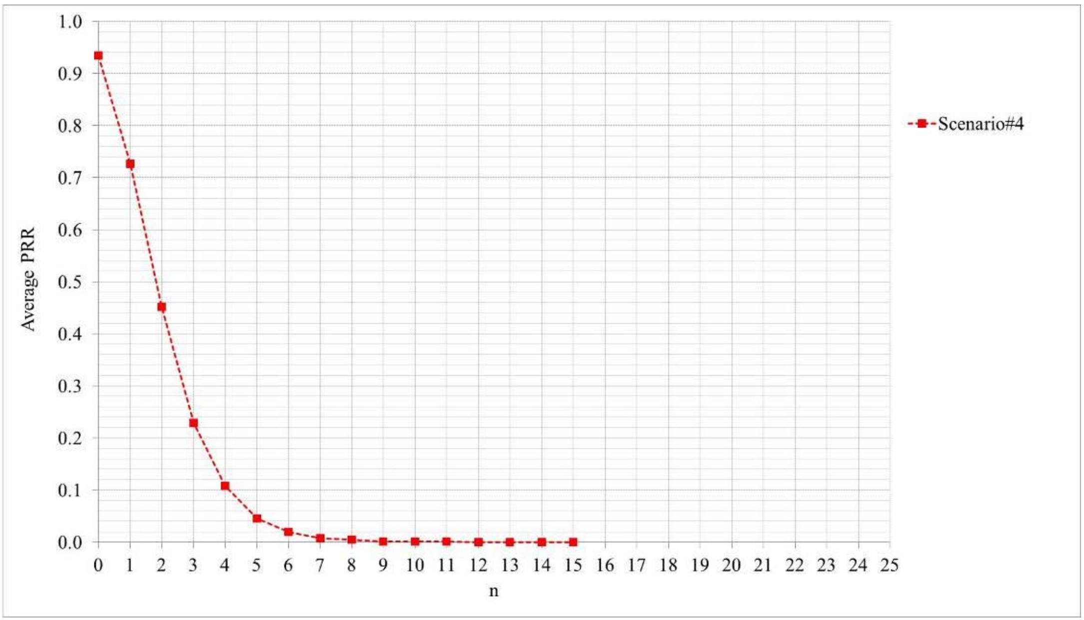
- Source 17



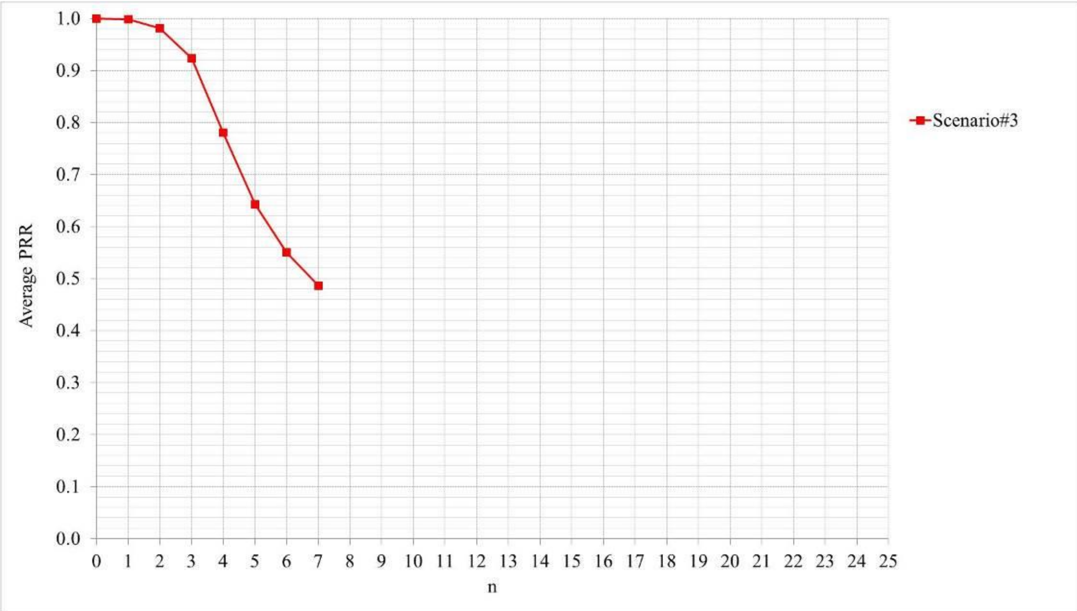
- V-UE RX of P-UE TX with V-UE TX
  - Source 1



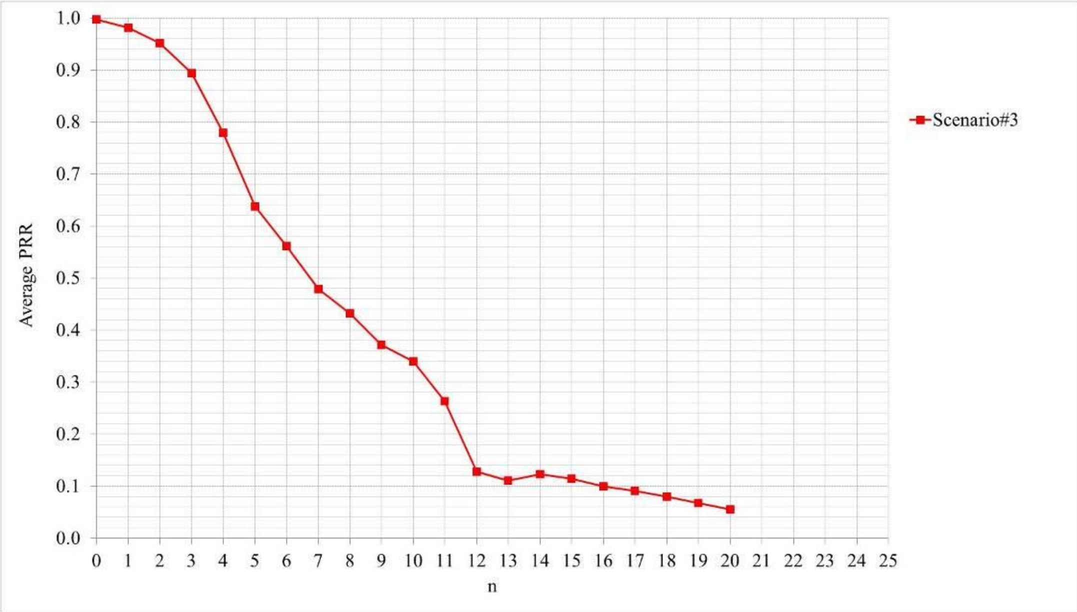
  - Source 3



- Source 4



- Source 5



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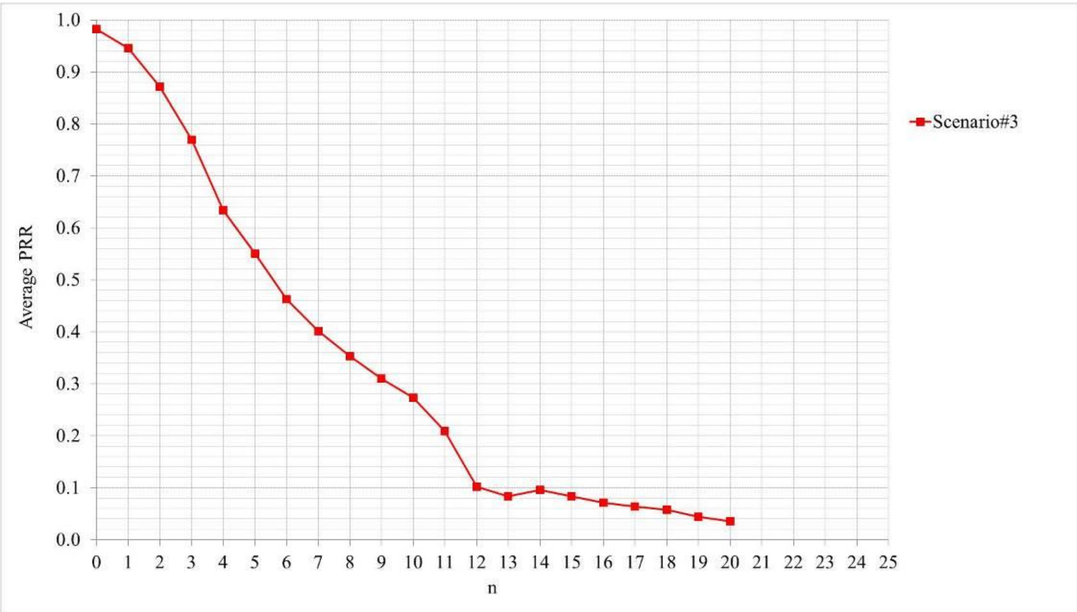
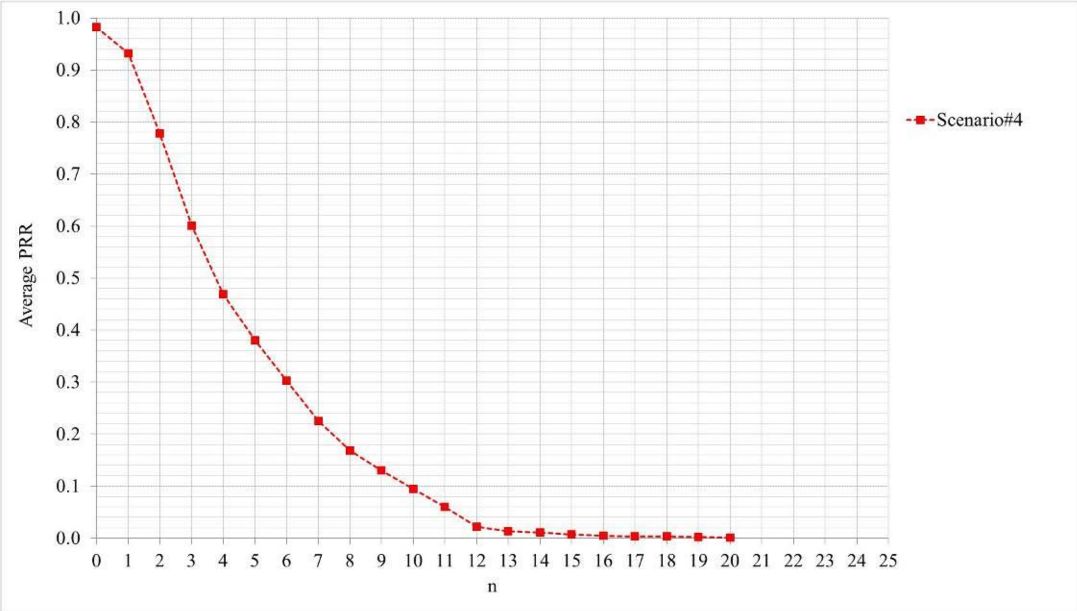


- Source 8



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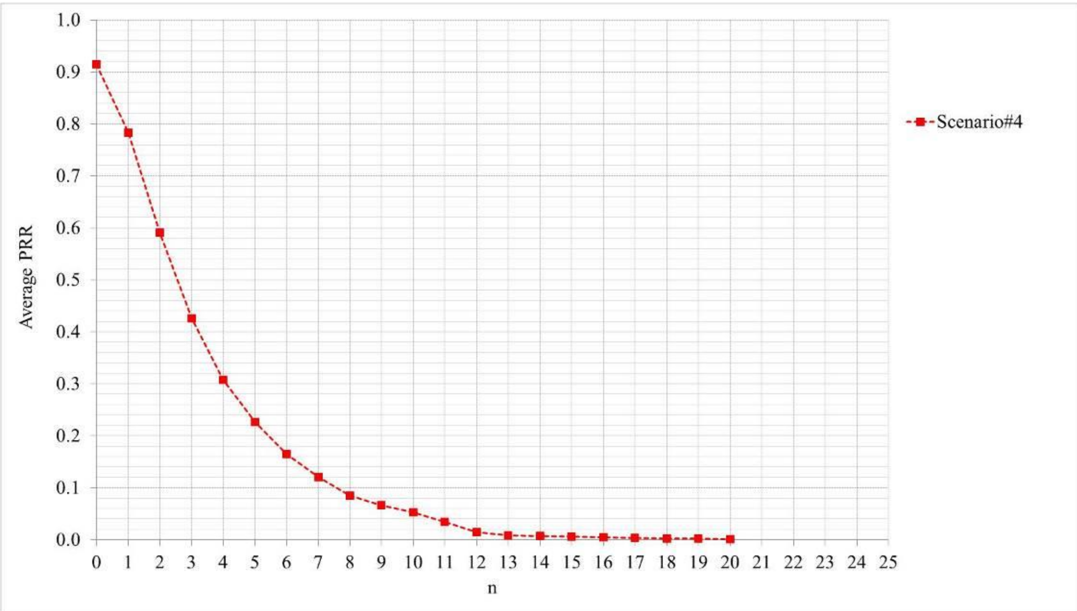

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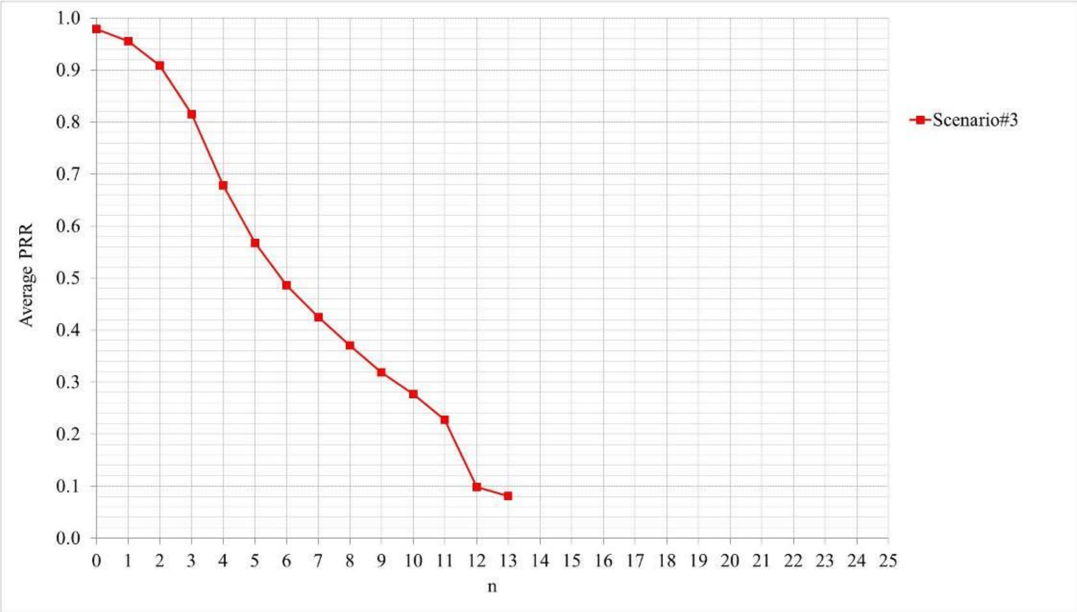

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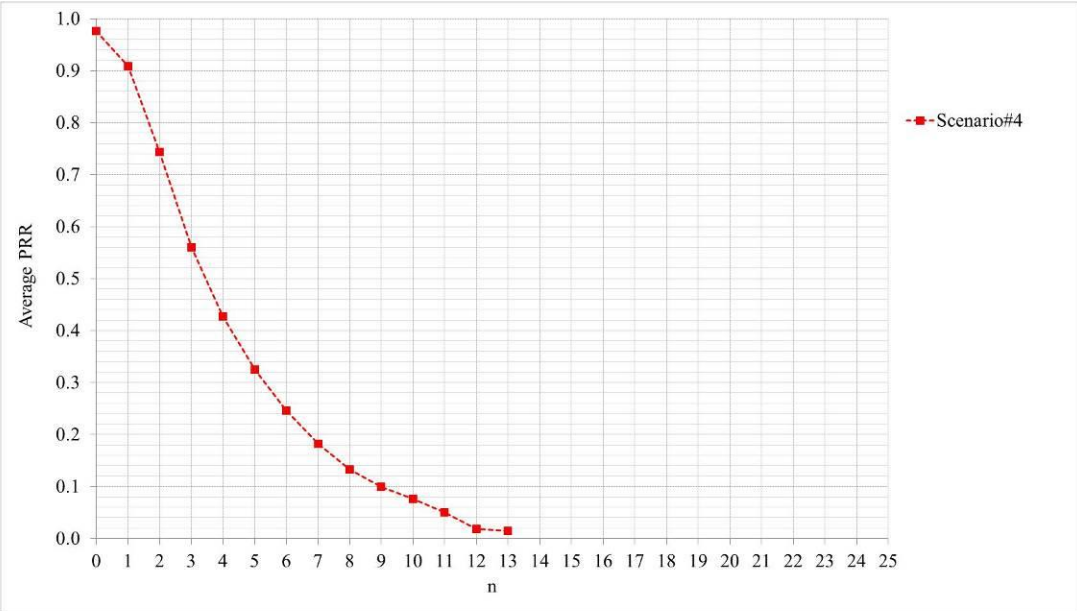

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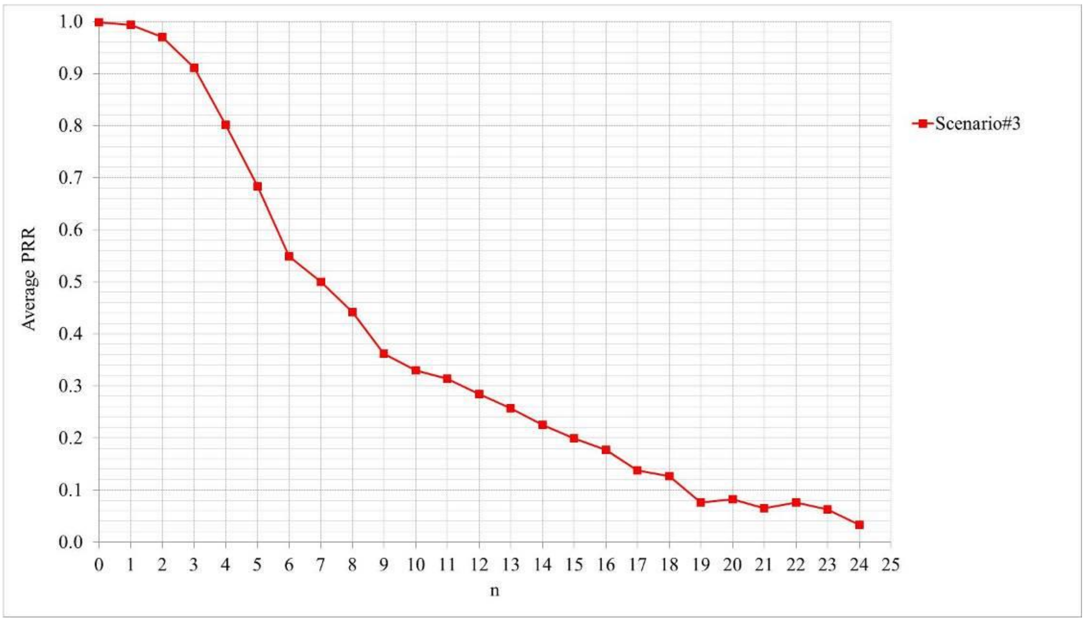

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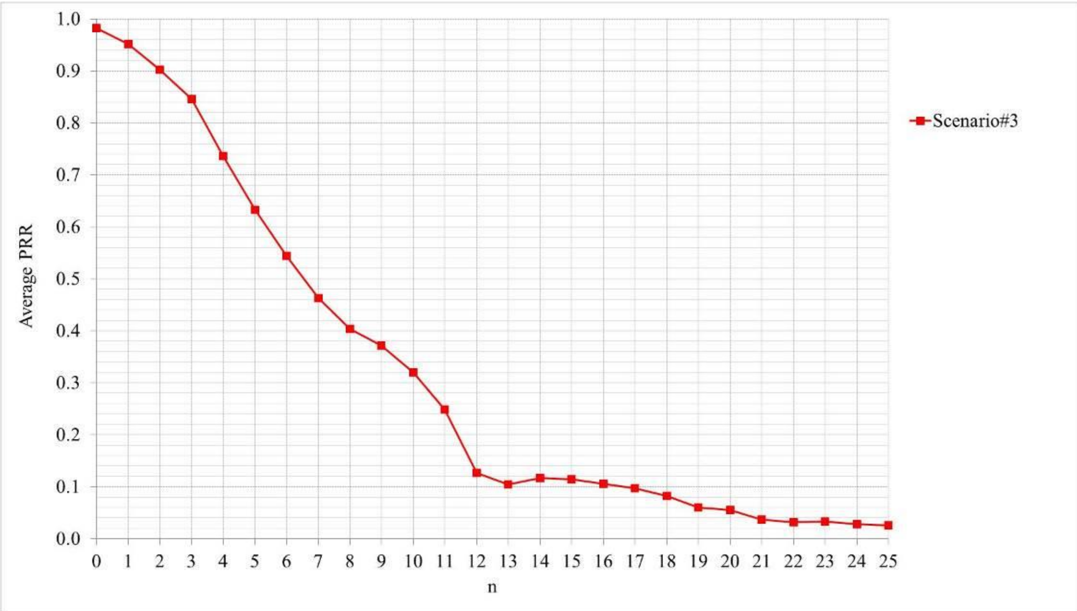

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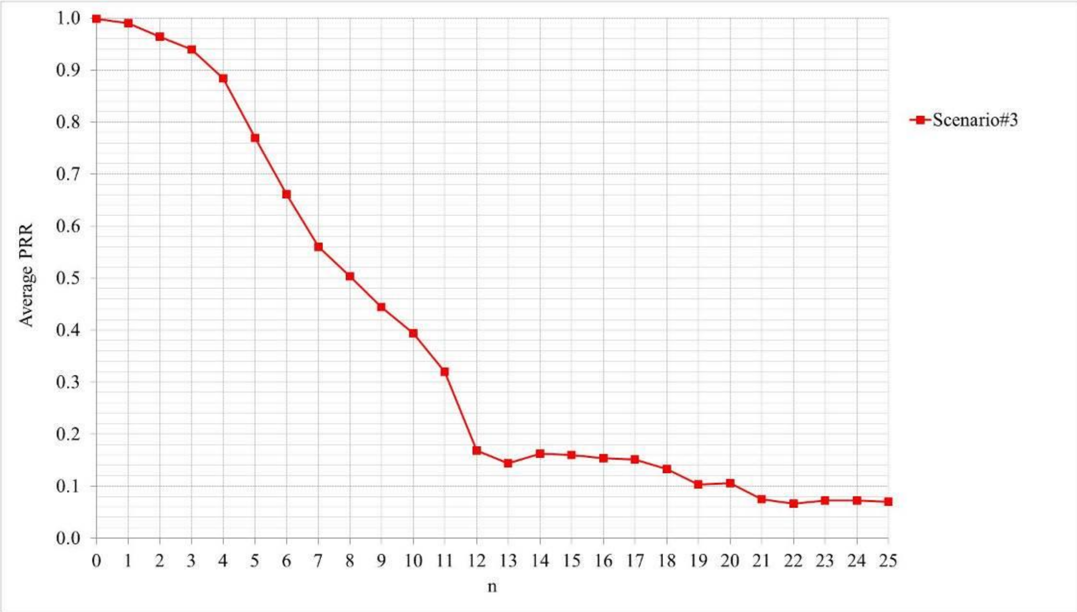

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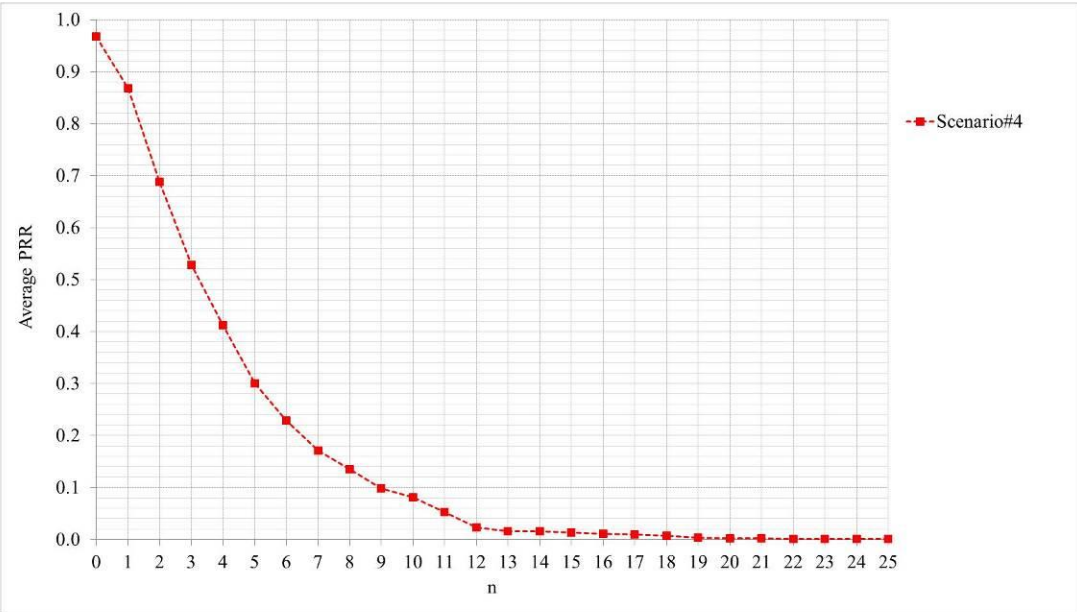

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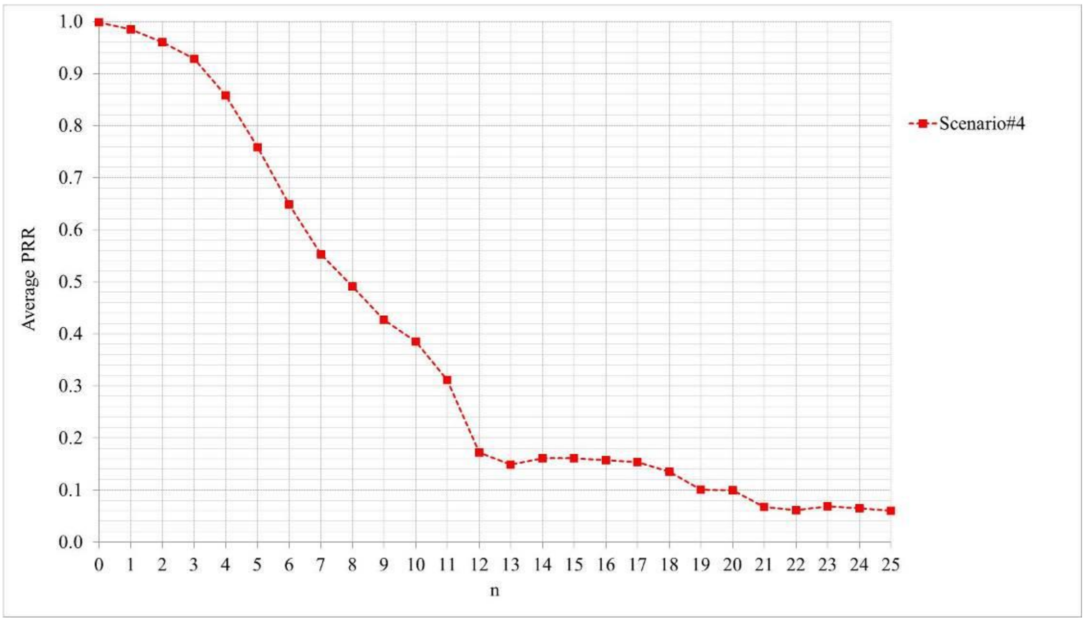

- P-UE RX of V-UE TX with P-UE TX
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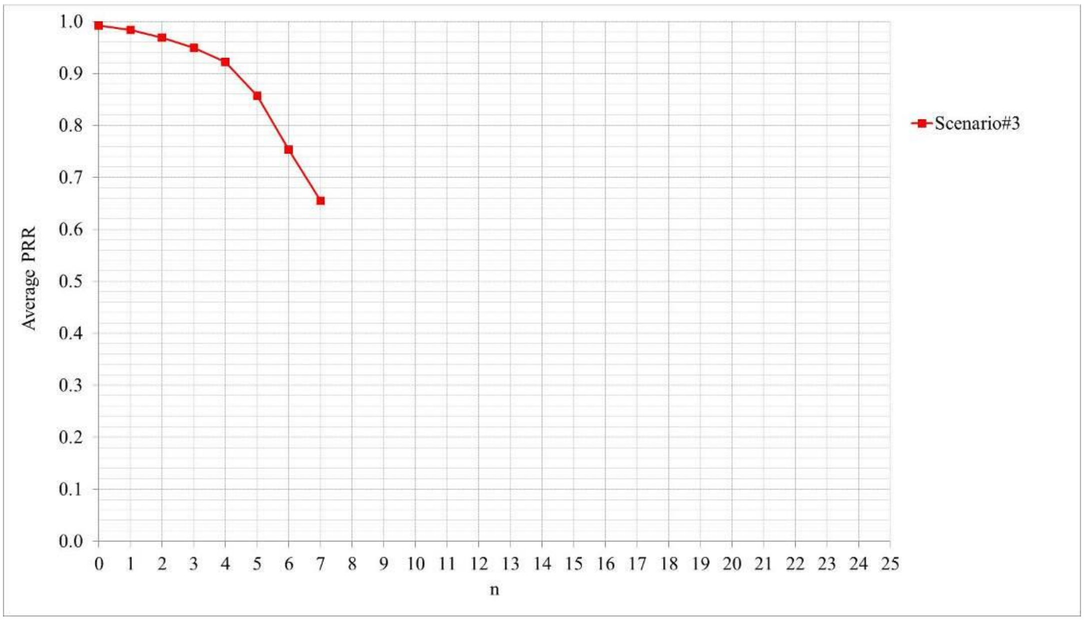

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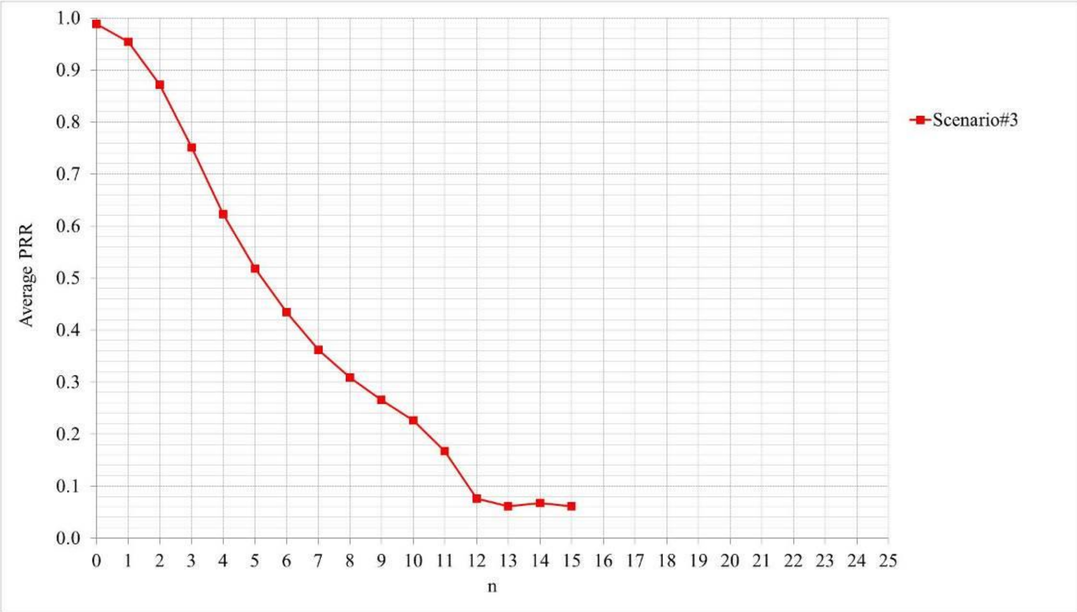

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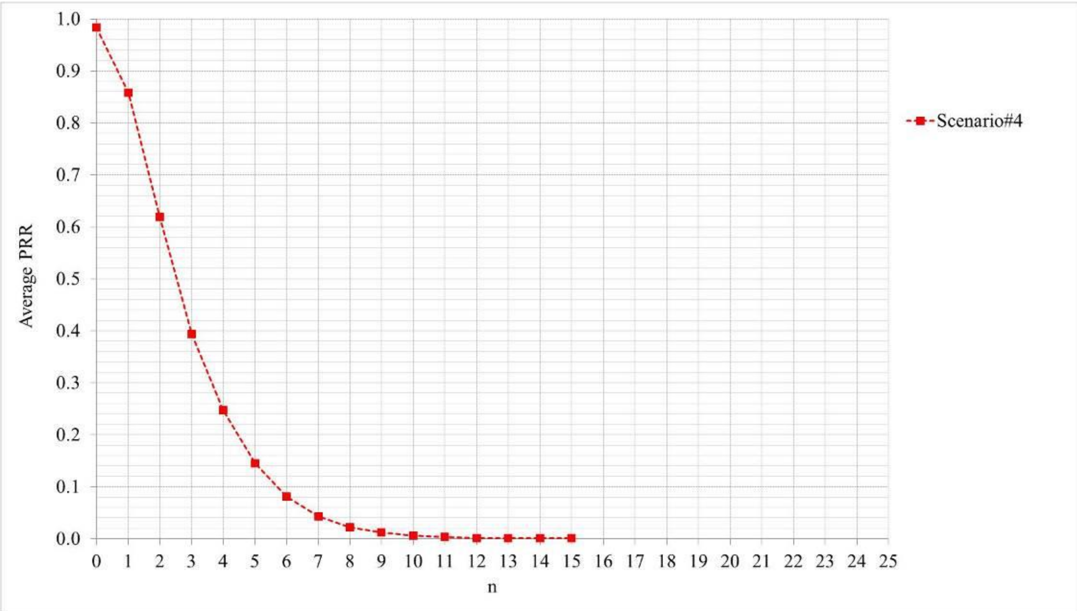

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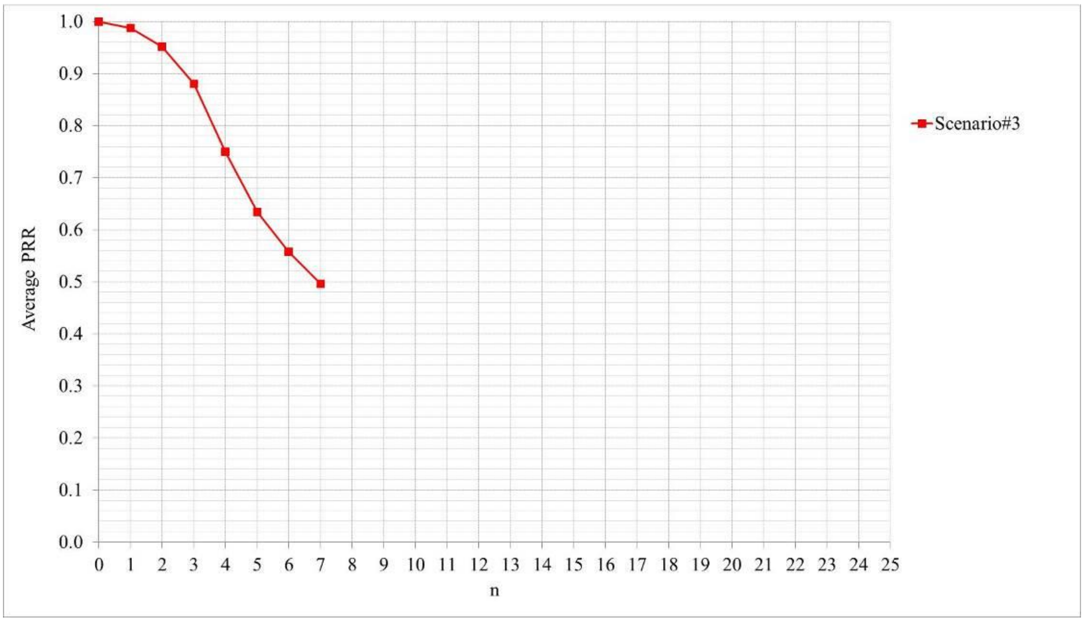

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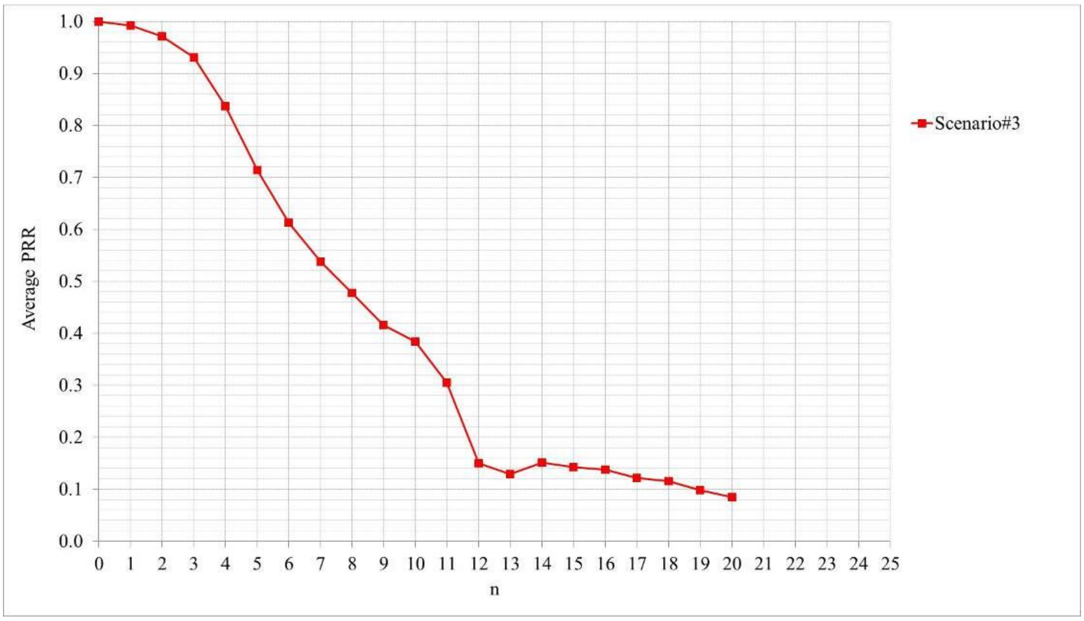

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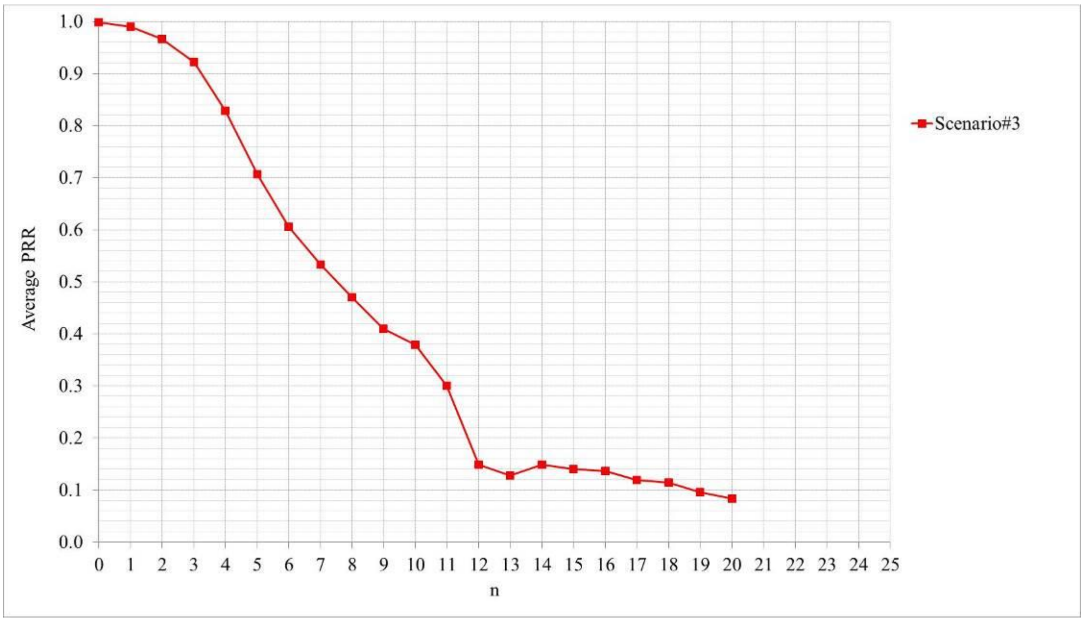

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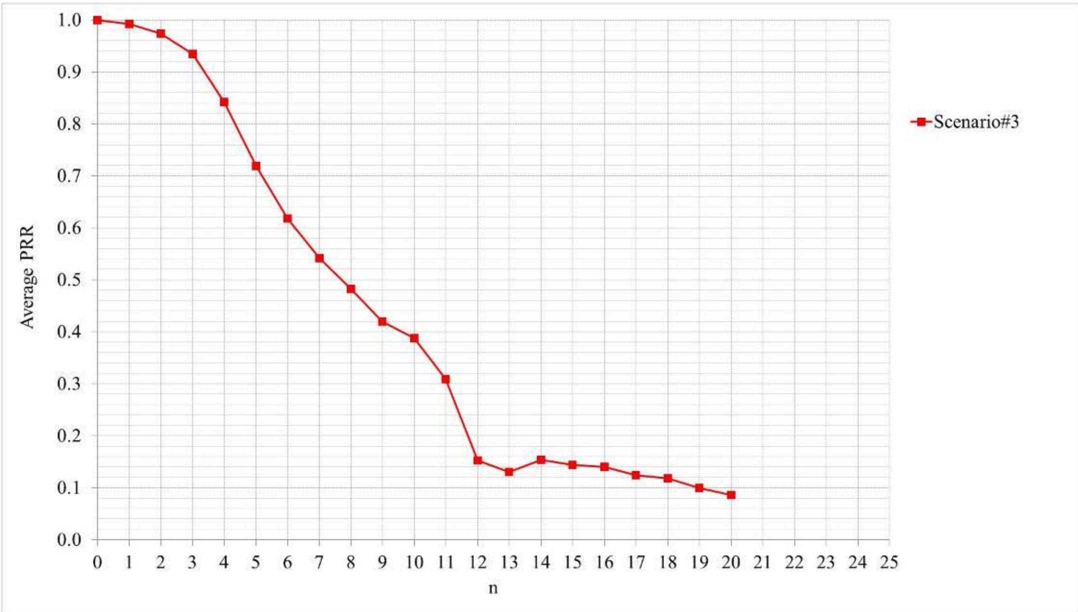

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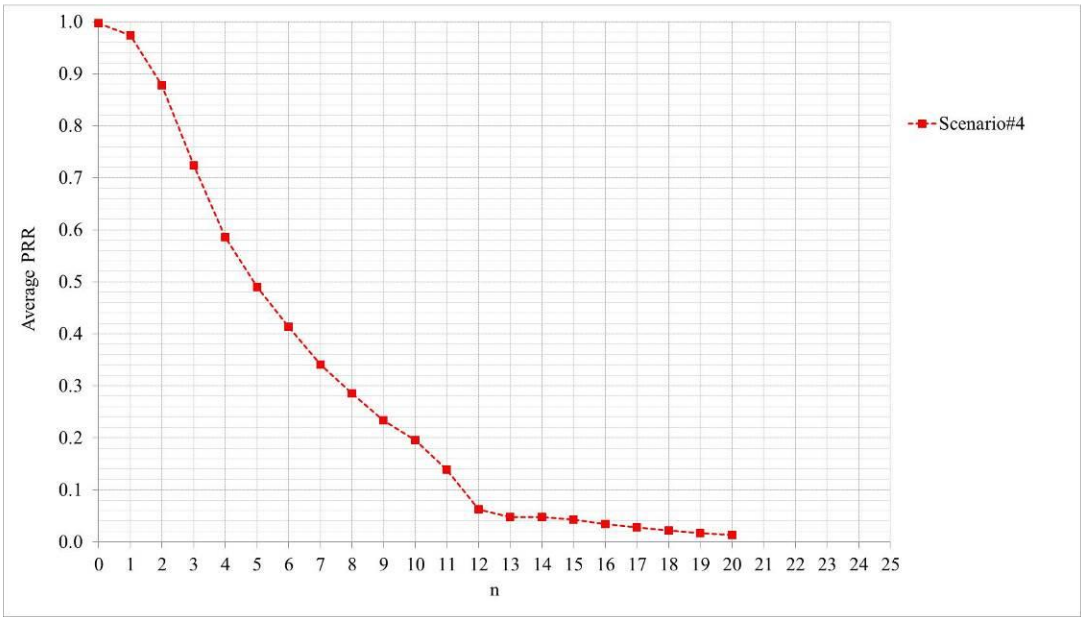

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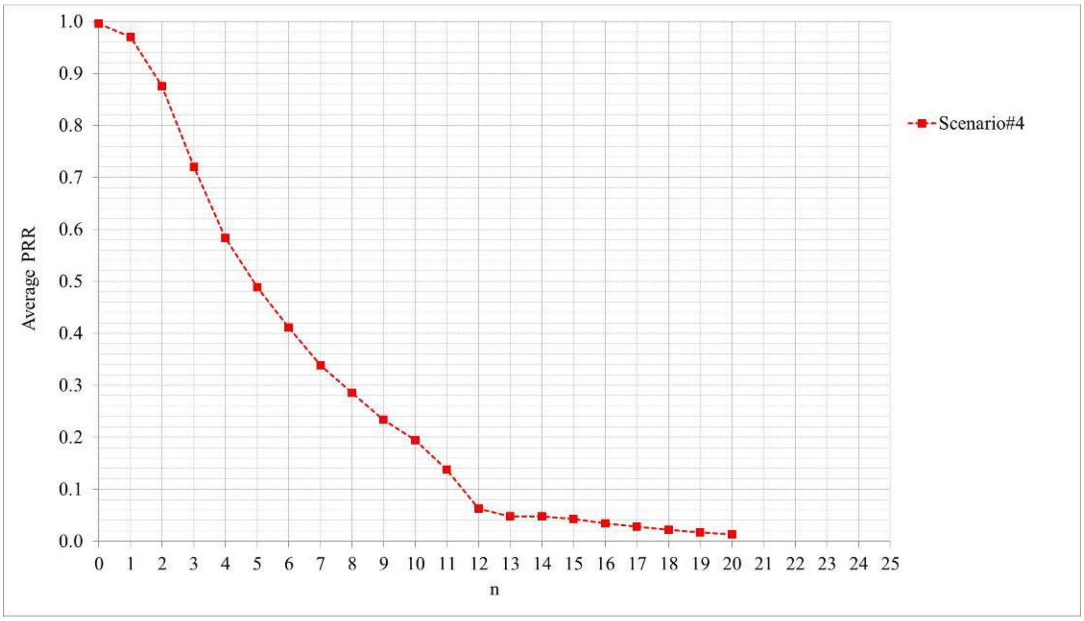

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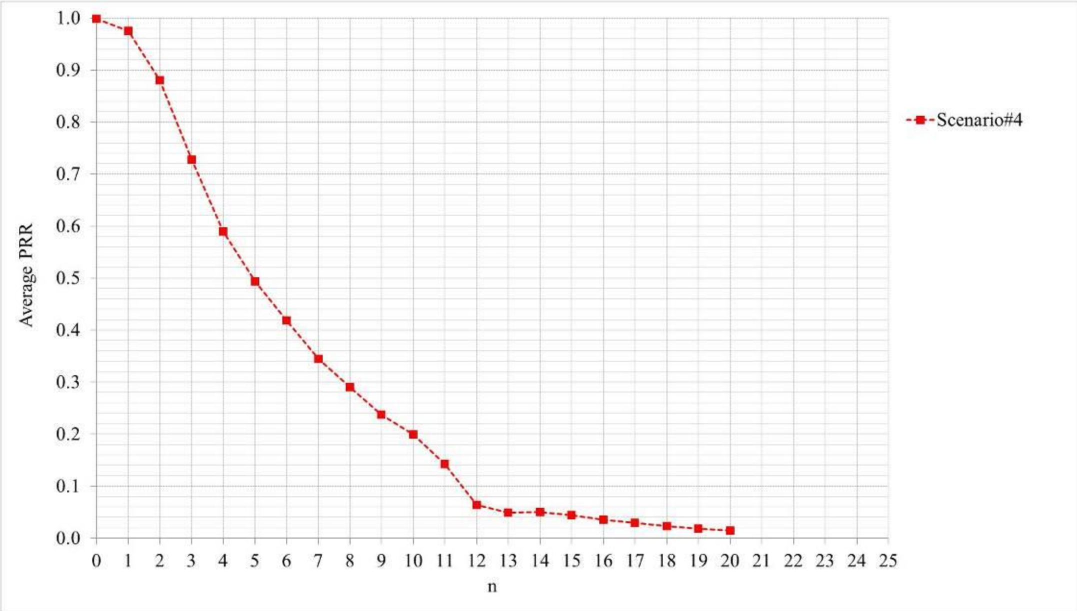

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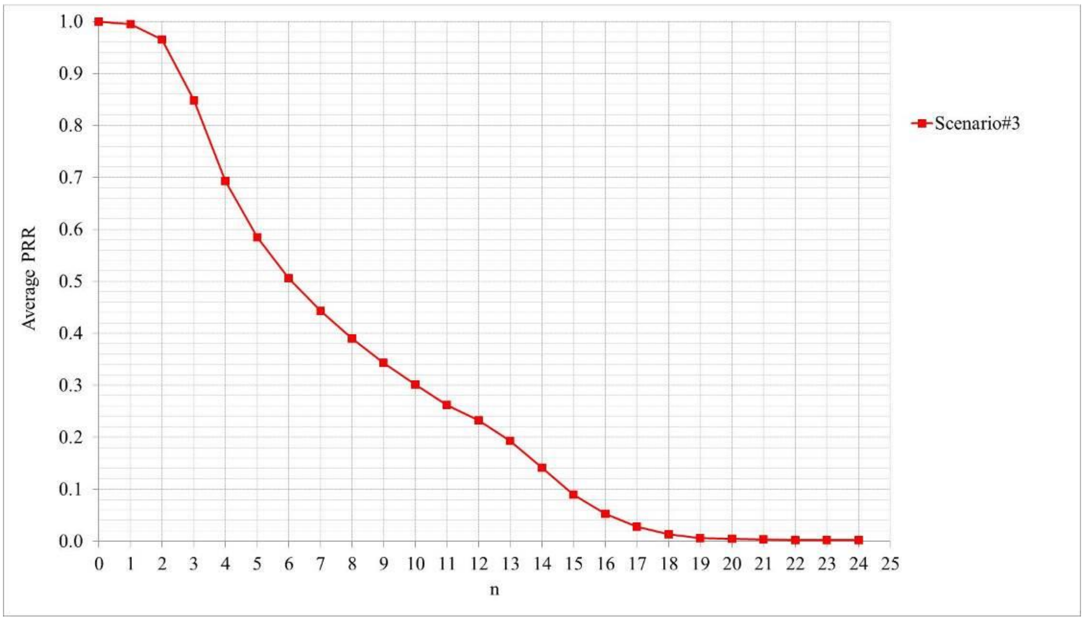

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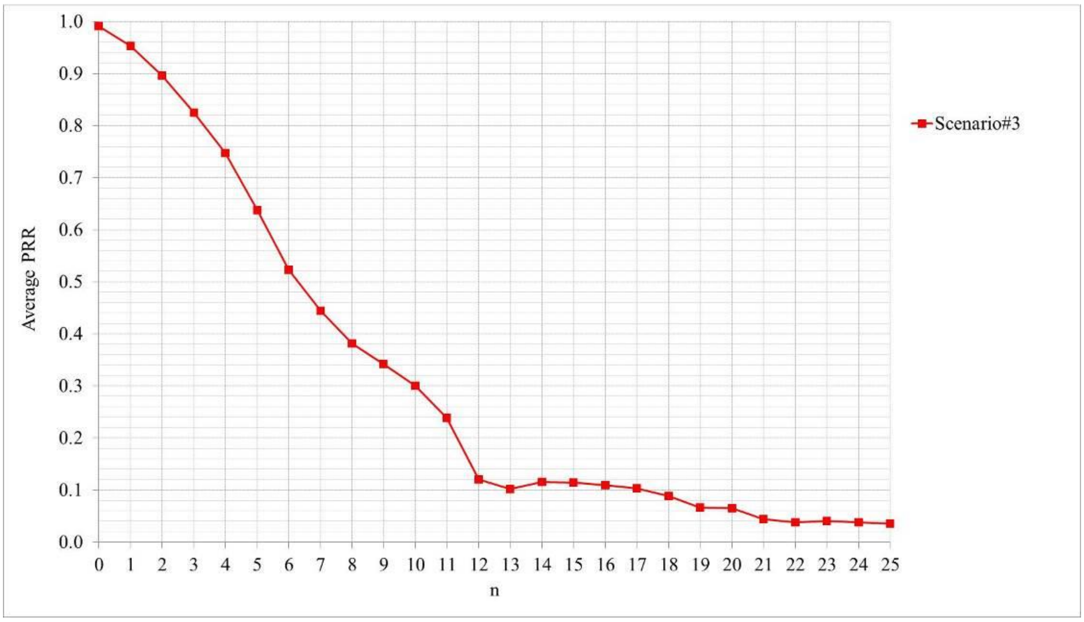

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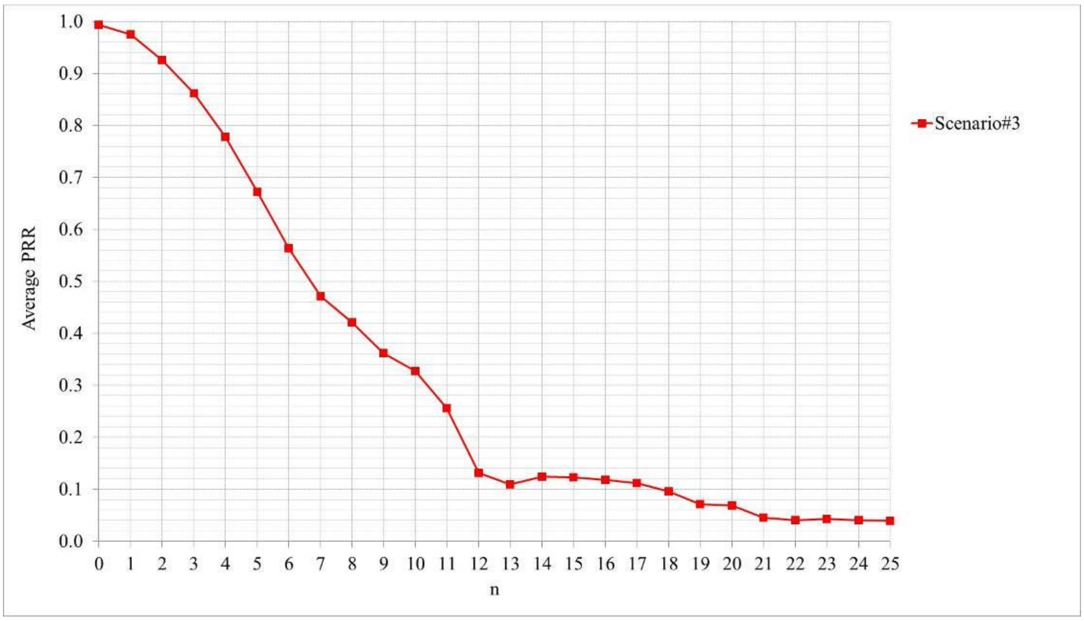

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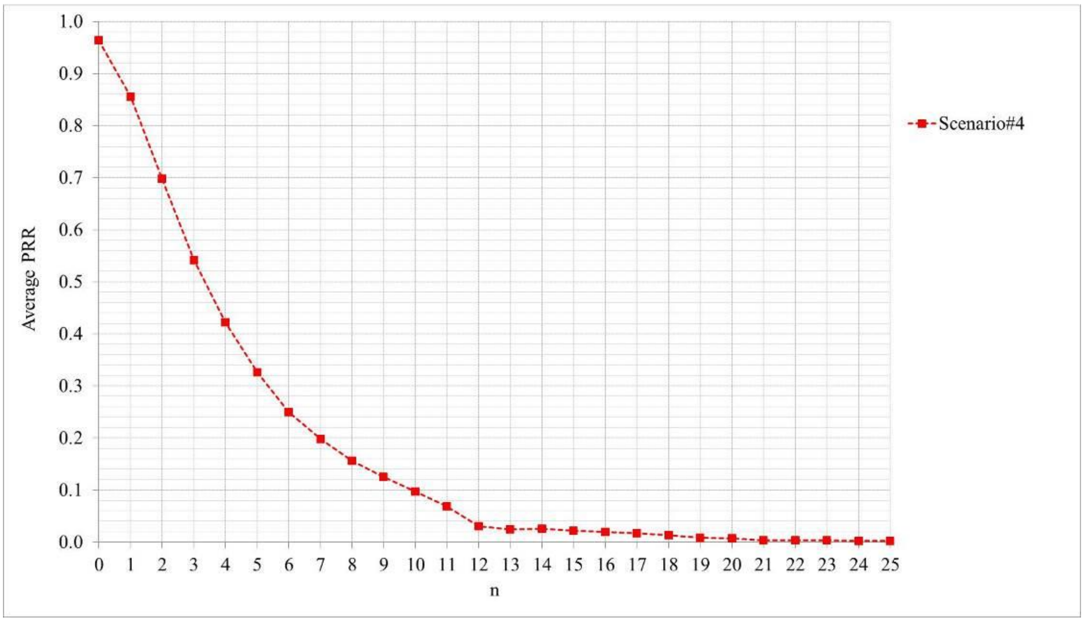

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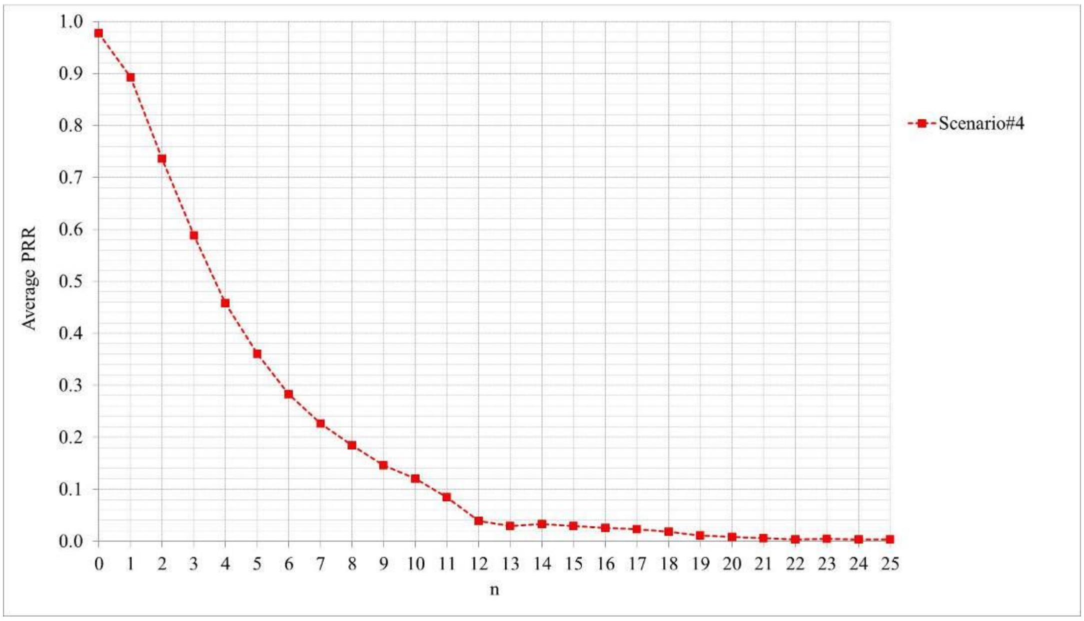

Annex G: Details of latency analysis

G.1 Scenarios for latency analysis

G.1.1 Latency decomposition of scenarios

It is assumed that sidelink communication is utilized for PC5 transport in the evaluation.

For V2V latency analysis, the overall latency of each scenario in section 4 can be decomposed into selective combination of the following latency components:

- **L-RRC** defined as the latency required for state transition from RRC_IDLE to RRC_CONNECTD and data bearer setup
  - This latency component addresses the time duration from the time UE starts RRC connection establishment to the time the UE has been configured with data bearer that is used to transport V2V messages.
- **L-paging** defined as the latency required for reception of paging message
  - This latency component addresses the time duration from the time paging message is arrived at eNB and to the time the UE successfully receives the paging message.
- **L-SL_config** defined as the latency required to configure sidelink configuration to a UE via dedicated signaling
  - This latency component addresses the time duration from the time UE sends SidelinkUEInformation for transmission resource request to the end time destination UE is configured with sidelink configuration via dedicated signaling.
- **L-SL** defined as the latency of SL transport between two UEs
  - This latency component addresses the time duration from the time UE has a V2V message to send over sidelink to the end time destination UE successfully receives the V2V message.
- **L-UL** defined as the latency of UL transport between UE and eNB
  - This latency component addresses the time duration from the time UE has a V2V message to send over UL to the time the eNB successfully receives the V2V message.
- **L-DL_uc** defined as the latency of unicast DL transport between eNB and UE
  - This latency component addresses the time duration from the time eNB has V2V message to send and to the time the UE successfully receives the V2V message over unicast DL.
- **L-DL_mbms** defined as the latency of MBMS transport between eNB and UE
  - This latency component addresses the time duration from the time eNB has V2V message to send and to the end time the UE successfully receives the V2V message over MBMS.
- **L-DL_scptm** defined as the latency of SC-PTM transport between eNB and UE
  - This latency component addresses the time duration from the time eNB has V2V message to send and to the end time the UE successfully receives the V2V message over SC-PTM.
- **L-NW_uc** defined as the latency of network processing in case of unicast transport for DL
  - This latency component addresses the time duration from the time of eNB reception of V2V message to the time the eNB is ready to transmit the V2V message over unicast DL.

Editor's note: In case the eNB that is supposed to transmit a concerned V2V message is different from the eNB that received the V2V message, L-NW_uc needs to consider the latency required for inter-eNB messaging. It is FFS whether the inter-eNB V2V messaging should be in the scope of this latency analysis.

- **L-NW_mbms** defined as the latency of network processing in case of MBMS transport for DL
  - This latency component addresses the time duration from the time of eNB reception of V2X message in UL to the time the eNB is ready to transmit the V2V message over MBMS DL.
- **L-NW_scptm** defined as the latency of network processing in case of SC-PTM transport for DL
  - This latency component addresses the time duration from the time of eNB reception of V2X message in UL to the time the eNB is ready to transmit the V2V message over SC-PTM DL.
- **L-RSU** defined as the latency of RSU(UE) processing
  - This latency component addresses the processing time at RSU side from the time the RSU successfully receives the V2V and the time the RSU is ready to transmit from upper layer point of view

With the latency decomposition, the end-to-end latency of each V2V scenario can be calculated as follows, where the component with parentheses is optional-present while component without parentheses is mandatory-present:

- **Scenario 1)** (L-RRC + L-SL_config) + L-SL
- **Scenario 2-1)** (L-RRC) + L-UL + L-NW_uc + (L-paging + L-RRC) + L-DL_uc
- **Scenario 2-2)** (L-RRC) + L-UL + L-NW_mbms + L-DL_mbms
- **Scenario 2-3)** (L-RRC) + L-UL + L-NW_scptm + L-DL_scptm
- **Scenario 3a-1)** (L-RRC + L-SL_config) + L-SL + L-RSU + (L-RRC) + L-UL + L-NW_uc + (L-paging + L-RRC) + L-DL_uc
- **Scenario 3a-2)** (L-RRC + L-SL_config) + L-SL + L-RSU + (L-RRC) + L-UL + L-NW_mbms + L-DL_mbms
- **Scenario 3a-3)** (L-RRC + L-SL_config) + L-SL + L-RSU + (L-RRC) + L-UL + L-NW_scptm + L-DL_scptm
- **Scenario 3b-1)** (L-RRC) + L-UL + L-NW_uc + (L-paging + L-RRC + L-SL_config) + L-DL_uc + L-RSU + L-SL
- **Scenario 3b-2)** (L-RRC) + L-UL + L-NW_mbms + L-DL_mbms + L-RSU + (L-RRC + L-SL_config) + L-SL
- **Scenario 3b-3)** (L-RRC) + L-UL + L-NW_scptm + L-DL_scptm + L-RSU + (L-RRC + L-SL_config) + L-SL

G.2 Analysis of latency component

This sub-clause provides the analysis of each latency component.

G.2.1 Scheduling policy and parameter values

Table G.2.1 summarizes scheduling policies and parameter values that are used throughout the analysis.

Table G.2.1 scheduling policy and parameter values used in the analysis

Parameters	Value(s)	Description
Scheduling policy for Uu	{ SPS, dynamic scheduling with BSR, dynamic scheduling without BSR}	For UL transmission, both SPS and dynamic scheduling are considered. For dynamic scheduling, both UL TX with a separate BSR and UL TX wih no separate BSR are considered.
Scheduling policy for SL	{ mode2, mode1}	Both UE autonomous scheduled SL TX and eNB scheduled SL TX are considered,
SR period	{ 1, 10}	Two values for scheduling request are considered.
SPS period	{10, 40, 80}	Three values for SPS period are considered.
Target BLER (%)	10	Target BLER is commonl applied for DL and UL transmission. A single value is considered.
backhaul delay for unicast	20	The latency for eNB-->SGW/PGW-->ITS AS--> SGW/PGW-->eNB that is considered in L-NW_uc, Fixed value of 20ms is assumed.
backhaul delay-sub_a for broadcast	15	The latency of eNB-->SGW/PGW-->ITS AS-->BM-SC. This parameter is used in L-NW_mbms, L-NW_scptm.
backhaul delay sub_b for	5	The latency comprising the latency for BMSC->eNB

broadcast		(including processing delays at BM-SC) This parameter is used in L-NW_mbms, L-NW_scptm.
MCH scheduling period (MSP)	40	A single value of MSP is considered.
SCPTM scheduling period (SSP)	{1, 10}	Two values are considered where t0ms corresponds to the case SCPTM DRX is not configured and 10ms corresponds to that the case SCPTM DRX is configured with 10ms SCPTM scheduling period.
Paging cycle	320	A single value is considered.
SC period	40	A single value is considered.
SCI time period	8	A single value is considered.
Upper layer processing	3ms	Application layer processing applicable for source UE, destination UE and RSU. A single value is considered.

G.2.2 Analysis of each component

G.2.2.1 L-RRC: RRC_IDLE to RRC_CONNECTD and data bearer setup

This latency component addresses the time duration from the time UE starts RRC connection establishment to the time the UE is configured with data bearer that is used to transport V2V message.

If UE is in RRC_IDLE, transmission or reception of V2V message via unicast requires the UE to make a RRC connection and establish dedicated data bearer to transport V2V message to/from network. Then the following latency component needs to be additionally considered when calculating overall latency for each scenario.

The latency of L-RRC is e presented in the following table.

Table G.2.2.1 L-RRC: Latency for RRC connection establishment and data bearer establishment

Sub-component	Time (ms)			Description
	Min	Mean	Max	
RRC_IDLE to RRC_CONNECTED + bearer setup	Mean	Max	50	50ms is the value for Rel-10 value referenced from Table 16.2.1-1 of 36.912.
Total	Mean	Max	50	

G.2.2.2 L-SL: SL transport between two UEs

This latency component addresses the time duration from the time UE has a V2V message to send over sidelink to the end time destination UE receives the V2V message.

The latency of L-SL with UE autonomous scheduled SL transmission (mode2) is presented in the following table.

Table G.2.2.2-a L-SL_mode2: Latency for V2V message transmission from V-UE to V-UE (RSU) via SLwith Mode2

Sub-component	Time (ms)			Description
	Min	Mean	Max	
SCI transmission	*SCI time period* + 4	(Min+Max)/2	*SC period* + *SCI time period* + 3	Min: 4 ms waiting after grant selection prior to actual SCI transmission + SCI time period Max: SC period waiting after grant selection prior to actual SCI transmission + SCI time period
SL data transmission	4	(Min+Max)/2	*SC period – SCI time period*	Min: corresponds to the case that first 4 subframes are used for transmission and 3 retransmissions. Max: corresponds to the case that a new transmission and 3 retransmission spans the whole data pool period.
L1/L2 RX UE processing	1.5	(Min+Max)/2	1.5	1.5ms for UE L1/L2 processing is assumed.
Upper layer RX UE processing	*upper layer processing*	(Min+Max)/2	*upper layer processing*	
Total	*SCI time period* + 9.5 + *upper layer processing*	(Min+Max)/2	2**SC period* + 4.5 + *upper layer processing*	

The latency of L-SL with eNB scheduled SL transmission (mode1) is presented in the following table.

Table G.2.2.2-b L-SL_mode1: Latency for V2V message transmission from V-UE to V-UE (RSU) via SL with Mode1

Sub-component	Time (ms)			Description
	Min	Mean	Max	
SL scheduling	Mean	16+*SR period*/2	16 +*SR period*	Referenced from step1-5 of Table A.1 in TR 36.881 with additional steps for BSR, as included in L-UL_dynamic_bsr: 1. Average delay to next SR opportunity SR periodicity/2 2. UE sends SR 1 TTI 3. eNB decodes SR and generates scheduling grant 3 TTI 4. Transmission of scheduling grant (assumed always error free) 1 TTI 5. UE processing delay (decoding scheduling grant + L1 encoding of data) 3 TTI 5.1. UE sends BSR 1TTI 5.2. eNB decodes SR and generates scheduling grant 3TTI 5.3. Transmission of scheduling grant (assumed always error free) 1TTI 5.4. UE processing delay (decoding scheduling grant + L1 encoding of data) 3 TTI
SCI transmission	Mean	*SCI time period* + 4	*SC period* + *SCI time period* + 3	Min: 4 ms waiting after grant selection prior to actual SCI transmission + SCI time period Max: SC period waiting after grant selection prior to actual SCI transmission + SCI time period
SL data transmission	Mean	4	SC period – SCI time period	Min value of 4 ms corresponds to the case that first 4 subframes are used for transmission and 3 retransmissions. Max value corresponds to the case that a new transmission and 3 retransmission spans the whole data pool period.
L1/L2 RX UE processing	Mean	1.5	1.5	1.5ms for UE L1/L2 processing is assumed.
Upper layer RX UE processing	Mean	*upper layer processing*	*upper layer processing*	
Total	Mean	*25.5 + SR period/2 + SCI time period + upper layer processing*	20.6+ *SR period* + 2**SC period + upper layer processing*	

G.2.2.3 L-UL_sps: UE to eNB via UL

This latency component addresses the time duration from the time UE has a V2V message to send over UL to the time the eNB successfully receives the V2V message, by using semi-persistent scheduling (SPS).

The latency of L-UL_sps is presented in the following table.

Table G.2.2.3 L-UL_sps: Latency for V2V message transmission from V-UE to eNB via UL with SPS

Sub-component		Time (ms)		Description
	Min	Mean	Max	
Uplink transmission	Mean	3+*SPS period*/2	3+*SPS period*	
Total	Mean	3+*SPS period*/2	3+*SPS period*	

G.2.2.4 L-UL_dynamic_nobsr: UE to eNB via UL with dynamic scheduling without a separate BSR

This latency component addresses the time duration from the time UE has a V2V message to send over UL to the time the eNB successfully receives the V2V message, by using dynamic scheduling without a separate BSR. The user plane latency for uplink transmission is based on the analysis in the Table A.1 of TR 36.881[2].

The latency of L-UL_ dynamic_nobsr is presented in the following table.

Table G.2.2.4 L-UL_dynamic_nobsr: Latency for V2V message transmission from V-UE to eNB via UL with dynamic scheduling without separate BSR

Sub-component	Time (ms)			Description
	Min	Mean	Max	
Uplink transmission	Mean	9.5+*SR period*/2 + (1+8**Target BLER*%/100)	9.5+*SR period* + (1+8**Target BLER*%/100)	Referenced from Table A.1 of TR 36.881: 1. Average delay to next SR opportunity SR periodicity/2 2. UE sends SR 1 TTI 3. eNB decodes SR and generates scheduling grant 3 TTI 4. Transmission of scheduling grant (assumed always error free) 1 TTI 5. UE processing delay (decoding Scheduling grant + L1 encoding of data) 3 TTI (1.5+1.5) 6. UE sends UL transmission (1 + p*8) TTI where p is initial BLER 7. eNB receives and decodes the UL data 1.5 TTI.
Total	Mean	9.5+*SR period*/2 + (1+8**Target BLER*%/100)	9.5+*SR period* + (1+8**Target BLER*%/100)	

G.2.2.5 L-UL_dynamic_bsr: UE to eNB via UL with dynamic scheduling with a separate BSR

This latency component addresses the time duration from the time UE has a V2V message to send over UL to the time the eNB successfully receives the V2V message, by using dynamic scheduling with a separate BSR.

The user plane latency for uplink transmission is based on the analysis in the Table A.1 of TR 36.881[2]

The latency of L-UL_ dynamic_bsr is presented in the following table.

Table G.2.2.5 L-UL_dynamic_bsr: Latency for V2V message transmission from V-UE to eNB via UL with dynamic scheduling with a separate BSR

Sub-component	Time (ms)			Description
	Min	Mean	Max	
Uplink transmission	Mean	17.5+*SR period*/2 + (1+8***Target BLER*%/100)	17.5+*SR period* + (1+8***Target BLER*%/100)	Referenced from Table A.1 of TR 36.881: 1. Average delay to next SR opportunity SR periodicity/2 2. UE sends SR 1 TTI 3. eNB decodes SR and generates scheduling grant 3 TTI 4. Transmission of scheduling grant (assumed always error free) 1 TTI 5. UE processing delay (decoding Scheduling grant + L1 encoding of data) 3 TTI (1.5+1.5) 5.1. UE sends BSR 1TTI 5.2. eNB decodes SR and generates scheduling grant 3TTI 5.3. Transmission of scheduling grant (assumed always error free) 1TTI 5.4. UE processing delay (decoding Scheduling grant + L1 encoding of data) 3TTI (1.5+1.5) 6. UE sends UL transmission (1 + p*8) TTI where p is initial BLER 7. eNB receives and decodes the UL data 1.5 TTI Note. Step 5.1 to 5.4 is added for the case the latency for BSR should be separately considered
Total	Mean	17.5+SR period/2 + (1+8*Target BLER%/100)	17.5+SR period + (1+8*Target BLER%/100)	

G.2.2.6 L-NW_uc: Network processing: from eNB (via ITS server) to eNB without passing through BM-SC (to use unicast DL)

This latency component addresses the time duration from the time of eNB reception of V2V message to the time the eNB is ready to transmit the V2V message over unicast DL.

It is assumed that the V2V message is travelling from eNB, then passing through S-GW/P-GW, ITS server, and is back to the eNB for unicast DL transmission. The latency calculation is based on TR 36.868[2]

The latency of L-NW_uc is presented in the following table.

Table G.2.2.6 L-NW_uc: Latency for network processing of received V2V message for unicast DL transmission

Sub-component	Time (ms)			Description
	Min	Mean	Time (ms)	
eNB→SGW/PGW→ITS AS→ SGW/PGW→eNB	Mean	Max	*backhaul delay for unicast*	
Total	Mean	Max	*backhaul delay for unicast*	

G.2.2.7 L-NW_mbms: Network processing: from eNB (via ITS server) to eNB with passing through BM-SC (to use MBMS DL)

This latency component addresses the time duration from the time of eNB reception of V2X message to the time the eNB is ready to transmit the V2V message over MBMS DL.

It is assumed that the V2V message is travelling from eNB and passing through S-GW/P-GW, ITS server, BM-SC and is back to the eNB for DL transmission.

The latency of L-NW_mbms is presented in the following table.

Table G.2.2.7 L-NW_mbms: Latency for network processing of received V2V message for MBMS transmission

Sub-component	Time (ms)			Description
	Min	Mean	Max	
eNB→SGW/PGW→ITS AS→BM-SC	Mean	Max	*backhaul delay sub_a*	
BM-SC → eNB	Mean	Max	*backhaul delay sub_b*	
Total	Mean	Man	*backhaul delay sub_a + backhaul delay sub_b*	

G.2.2.8 L-NW_scptm: Network processing: from eNB (via ITS server) to eNB with passing through BM-SC (to use SCPTM DL)

This latency component addresses the time duration from the time of eNB reception of V2X message to the time the eNB is ready to transmit the V2V message over SCPTM DL.

It is assumed that the V2V message is travelling from eNB and passing through S-GW/P-GW, ITS server, BM-SC and is back to the eNB for DL transmission.

The latency of L-NW_scptm is presented in the following table.

Table G.2.2.8 L-NW_scptm: Latency for network processing of received V2V message for SCPTM transmission

Sub-component	Time (ms)			Comments
	Min	Mean	Max	
eNB→SGW/PGW→ITS AS→BM-SC	Mean	Max	*backhaul delay sub_a*	
BM-SC → eNB	Mean	Max	*backhaul delay sub_b*	
Total	Mean	Max	*backhaul delay sub_a + backhaul delay sub_b*	

G.2.2.9 L-DL_uc: eNB to UE via unicast DL

This latency component addresses the time duration from the time eNB has V2V message to send and to the time the UE receives the V2V message over unicast DL.

It is assumed that all UEs (vehicles or RSU) are in RRC_CONNECTED so that the latency required for idle to connected state and dedicated bearer setup is not considered. User plane latency from eNB to UE over unicast DL is based on the analysis in the section A1.1 of TR 36.881[3].

The latency of L-DL_uc is presented in the following table.

Table G.2.2.9 Latency for V2V message transmission from eNB to V-UE via unicast DL

Sub-component	Time (ms)			Description
	Min	Mean	Max	
eNB → destination UE	Mean	Max	4+8**Target BLER*(%)/100	Step for DL transmission (Section A1.1 of TR36.881): 1. 1.5 TTI for eNB processing and scheduling 2. (1+p*8) TTI for eNB transmission with p is initial BLER 3. 1.5 TTI for UE L1/L2 processing
RX UE processing	Mean	Max	upper layer processing	\
Total	Mean	Max	4+8**Target BLER*(%)/100 + upper layer processing	

G.2.2.10 L-DL_mbms: eNB to UE via MBMS DL

This latency component addresses the latency from when a V2X message to send arrives at the eNB to when the UE successfully receives the V2V message over MBMS. This latency component comprises the followings:

- L_DL_mbms_a: Latency due to buffering packets at the eNB waiting for next MSP. Depending on when the packet is received from the BM-SC, L_DL_mbms_a varies from MSP to 1ms;
- L_DL_mbms_b: within the MSP, time to wait for the MTCH transmission opportunity. It can vary from 1ms to MSP depending on where MTCH subframes are located in the MSP.

Based on this analysis, the latency of L-DL_mbms is presented in the following table.

Table G.2.2.10 L-DL_mbms: Latency for V2V message transmission from eNB to V-UE via MBMS

Sub-component	Time (ms)			Description
	Min	Mean	Max	
Wait for MTCH opportunity	2	MSP/2+1	MSP+1	Depending on packet arrival time at eNB and MCH Scheduling Period (MSP)
DL transmission	2.5	2.5	2.5	Assumed 1ms TTI and 1.5ms UE L1/L2 processing time
RX UE processing	upper layer processing	upper layer processing	upper layer processing	
Total	4.5+ upper layer processing	3.5+MSP/2 + upper layer processing	3.5+MSP + upper layer processing	

G.2.2.11 L-DL_scptm: eNB to UE via SCPTM DL

This latency component addresses the latency from when the packet arrives at the eNB to when the UE successfully receives the V2V message over SCPTM. This latency component comprises the followings:

- L_DL_scptm_a: Latency due to buffering packets at the eNB waiting for next SSP. Depending on when the packet is received from the BM-SC, L_DL_sptm_a varies from SSP to 1ms;
- L_DL_scptm_b: within the SSP, time to wait for the SCPTM transmission opportunity. It can vary from 1ms to SSP depending on where SCPTM subframes are located in the SSP.

The latency of L-DL_scptm is presented in the following table.

Table G.2.2.11 L-DL_scptm: Latency for V2V message transmission from eNB to V-UE via SCPTM

Sub-component	Time (ms)			Description
	Min	Mean	Max	
Wait for SCPTM opportunity	2	max(SSP/2+1,2)	SSP+1	Depending on packet arrival time at eNB and SCPTM Scheduling Period (SSP)
DL transmission	2.5	2.5	2.5	1ms TTI and 1.5ms UE L1/L2 processing time are assumed
RX UE processing	upper layer processing	upper layer processing	upper layer processing	
Total	4.5 + upper layer processing	2.5+max(SSP/2+1,2)+upper layer processing	3.5+SSP)+upper layer processing	

G.2.2.12 L-paging: Reception of paging message

This latency component addresses the time duration from the time paging message is arrived at eNB and to the time the UE successfully receives the paging message.

The latency of L-paging is presented in the following table.

Table G.2.2.12 L-paging: Latency for reception of paging message

Sub-component	Time (ms)			Description
	Min	Mean	Max	
paging cycle	Mean	*paging cycle* /2	*paging cycle*	
eNB → UE	Mean	2.5	2.5	Assumed 1ms TTI and 1.5ms UE L1/L2 processing time
Total	Mean	*paging cycle*/2 + 4	*paging cycle* + 4	

G.2.2.13 L-SL_config: Reception of sidelink configuration via dedicated signaling

This latency component addresses the time duration from the time UE sends SidelinkUEInformation for transmission resource request to the end time destination UE is configured with sidelink configuration via dedicated signaling.

The latency of L-SL_config is presented in the following table.

Table G.2.2.13 L-SL_config: Latency for reception of sidelink configuration via dedicated signalling

Description	Time (ms)			Description
	Mean	Mean	Max	
L-UL_dynamic_bsr	Mean	Max	17.5+*SR period*/2 + (1+8**Target BLER*%/100)	Transmission of SidelinkUEInformation See the description for latency component, L-UL_dynamic_bsr
eNB → destination UE	Mean	Max	4+8*Target BLER(%)/100	Reception of RRCConnectionReconfiguration including dedicated sidelink configuration See the description for latency sub-component, eNB → destination UE in the L-DL_uc
Total	Mean	Max	*22.5 + SR period/2 + 16*Target BLER%/100*	

G.2.2.14 L-RSU: RSU processing

Table G.2.2.14 L-RSU: RSU processing:

Sub-component	Time (ms)			Description
	Min	Mean	Max	
RSU processing	Mean	Max	*upper layer processing*	Upper layer processing timer as defined in section 3.1 is assumed
Total	Mean	Max	*upper layer processing*	

Annex H: Traffic Characteristics of CAM

The following section summarizes the traffic characteristics of CAM messages, including the triggering, generation, and expected size of these messages.

According to [28], the CAM generation trigger conditions of a UE shall be as follows:

1) The time elapsed since the last CAM generation is equal to or greater than a DCC (decentralized congestion control) related interval (i.e. *T_GenCam_Dcc* [28]) and one of the following conditions related to UE dynamics is given: the distance between the current position of the UE and the position included in the CAM previously transmitted by the UE exceeds 4 m; or the absolute difference between the current heading of the UE and the heading included in the CAM previously transmitted by the UE exceeds 4°; or the absolute difference between the current speed of the UE and the speed included in the CAM previously transmitted by the UE exceeds 0,5 m/s.

2) The time elapsed since the last CAM generation is equal to or greater than the currently valid upper limit of the CAM generation interval (i.e. *T_GenCam* [28]) and equal to or greater than DCC related interval *T_GenCam_Dcc*.

If one of the above two conditions is satisfied, a CAM shall be generated immediately.

Besides, the CAM generation interval shall not be inferior to the lower limit of 100 ms and shall not be superior to the upper limit of 1000 ms. The value range of *T_GenCam_DCC* shall be limited to 100 ms ≤ *T_GenCam_DCC* ≤ 1000 ms. The parameter *T_GenCam* shall be set to the time elapsed since the last CAM generation, if a CAM is triggered due to above condition 1). After triggering a number of consecutive CAMs (i.e. *N_GenCam* consecutive CAMs [28]) due to condition 2), *T_GenCam* shall be set to 1000 ms. The value of the parameter *N_GenCam* can be dynamically adjusted according to some environmental conditions. The default and maximum value of *N_GenCam* shall be 3.The conditions for triggering the CAM generation shall be checked repeatedly every *T_CheckCamGen* which acts as the check period. The check period *T_CheckCamGen* shall be equal to or less than 100 ms.

With above CAM generation trigger conditions [28], the CAM characteristics are captured as follows.

In scenarios with relative stable vehicle dynamics (e.g. highway), the main trigger for CAM generation is the change of position, i.e. the distance between the current position of the UE and the position included in the CAM previously transmitted by the UE exceeds 4 m, and as such is the main factor affecting the periodicity of the CAM. The triggering conditions of speed change and heading change generate only a few CAMs occasionally, and mainly influence the timing of the CAM traffic.

The period of the CAM typically changes when the vehicle's speed change exceeds a range.

The period of the CAM remains unchanged and therefore the CAM can be regarded as periodical with a certain periodicity when the vehicle is travelling at a relatively stable speed within a certain range which depends on vehicle speed.

A speed change or heading change is likely to affect the timing offset of a series of CAMs occasionally, and such timing offset change may lead to misalignment between SPS timing and CAM timing which further results in the risk of the V2X delay requirement not being satisfied.

In addition, the CAM message size is variable. The CAM message size is about 121 ~ 320 Bytes without certificate and about 230 ~ 429 Bytes with certificate

Annex I: Change history

Change history							
Date	**TSG #**	**TSG Doc.**	**CR**	**Rev**	**Subject/Comment**	**Old**	**New**
2015-08		R1-154285			TR skeleton		0.0.1
2015-09		R1-155020			MCC: correction of release impacted on coverpage	0.0.1	0.0.2
2015-10		R1-155411			Inclusion of evaluation assumptions after RAN1#82	0.0.2	0.1.0
2015-11		R1-156890			Inclusion of TPs agreed in R1-155412 and R1-156382	0.1.0	0.2.0
2015-11		R1-157850			Inclusion of agreements reached during RAN1#83	0.2.0	0.4.0
2016-02		R1-161565			Inclusion of TPs agreed in R1-161468, R1-161486, R2-161678, and R2-162058.	0.4.0	0.5.0
2016-03		RP-160439			Submission to TSG RAN for information	0.5.0	1.0.0
2016-05		R1-164532			Inclusion of TPs agreed in R1-163940, R2-163650, R2-164495, R2-164497, R2-164553, and R3-161404 with the text agreed in the email discussion [85-12] and editorial changes	1.0.0	2.0.0