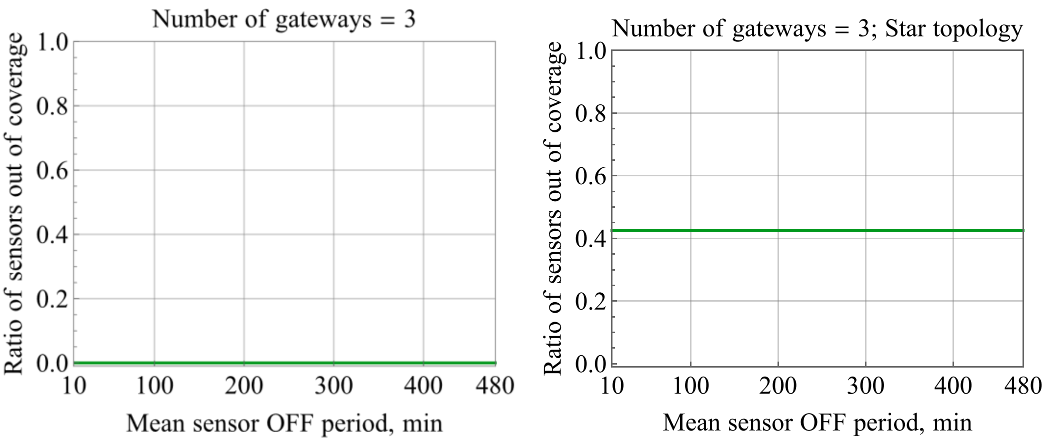


Figure 11: ITU-R configuration (700MHz, 25m antenna height): Out of coverage probability: Left Mesh – right Star (Direct link to Sink allowed)

Results based on DECT configuration

Figure 12 below presents the out of coverage probability of the devices in star topology (right) and in mesh topology (left) in a given environment with DECT configuration (1900MHz, 5m antenna height). The figure shows that with current link performance (based on link level simulations and with low antenna gains) the link budget is not sufficient if only direct connection to BTS (sink/gateway) are possible, as more than 50% of devices are out of coverage (devices are uniformly distributed in the area). However, when multi-hop connections with mesh-topology are enabled, every device can connect to the sink and no outage is experienced.

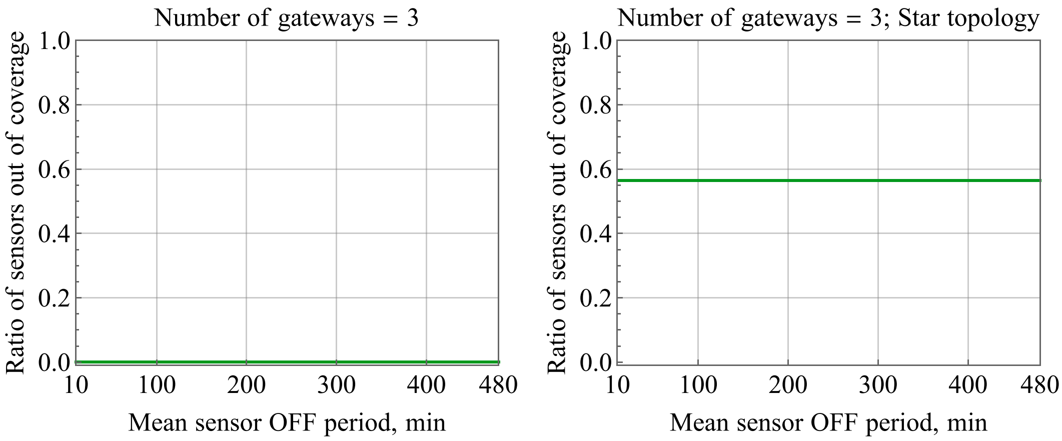


Figure 12: DECT configuration (1900MHz, 5m antenna height): Out of coverage probability: Left Mesh – right Star (Direct link to Sink allowed)

Discussion

It should be noted that x-axels in Figure 11 and Figure 12, "Mean sensor OFF period" is the time interval between two packets being generated, i.e. 1 packet every 0.116 h refers 10 min in the figure, and 120 min present 2 hours. The link budget calculations explains the high out of service probability for the star topology case as the maximum NLOS link distance covers roughly 27% of the cell area in DECT configuration. When antenna height is incresed and operating band is changed to 700 MHz, the out of coverage probability is significantly reduced in star topology as bit more than 40% of devices are out of coveage thanks to improved link budget. For mesh topology the out of coverage is 0% for both system parameterisations.

Conclusion 1: Results for cell area reliablity: 100%, due to multihop mesh for both ITU-R WPD5 and DECT configurations.

Packet drop ratio analysis

Results based on ITU-R configuration

Figure 13 presents the packet drop ratio (for end-to-end connection) as number of packets per second received by each sector (sink). The green dot shows the ITU-R requirement limit of 10 packets/second, i.e. each 1 000 000 devices per km^2 creates one packet in every 2 hours.

For ITU-R scenario using 700 MHz frequency band and 25 m antenna height results are presented in Figure 13 and Table 13 summarizes the obtained results respectively.

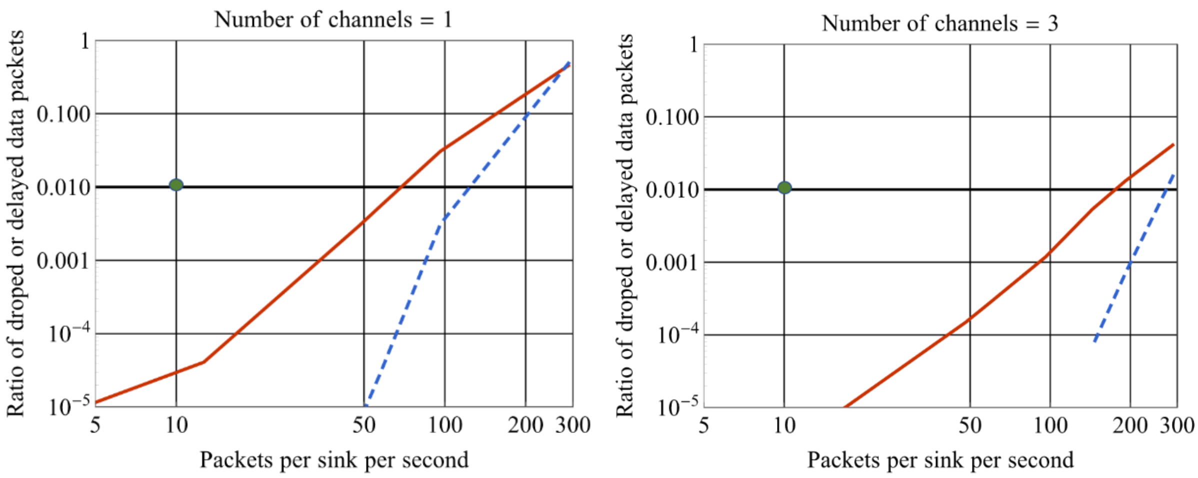


Figure 13: ITU-R configuration: Data Packet Drop ratio (end-to-end) (lost or delayed >10 seconds): Left side 1 channel, Right side 3 channels. Red line: 3 ARQ attempts, Blue line 8 ARQ attempts per hop (no combining)

Table 13: ITU-R configuration: Number of packets/second/sink or mean packet interval with 1 000 000 devices per km^2

	3 ARQ attempts	**8 ARQ attempts**
1 channel	69 pps or 1 message / 17.4 minutes/device	124 pps or 1 message / 9.7 minutes/device
3 channels	178 pps or 1 message / 6.8 minutes/device	274 pps or 1 message / 4.4 minutes/device

Results based on DECT configuration

Similarly to previous section, Figure 14 presents the packet drop ratio (for end-to-end connection) as number of packets per second received by each sector (sink). The green dot shows the ITU-R requirement limit of 10 packets/second, i.e. each 1 000 000 devices per km^2 creates one packet in every 2 hours.

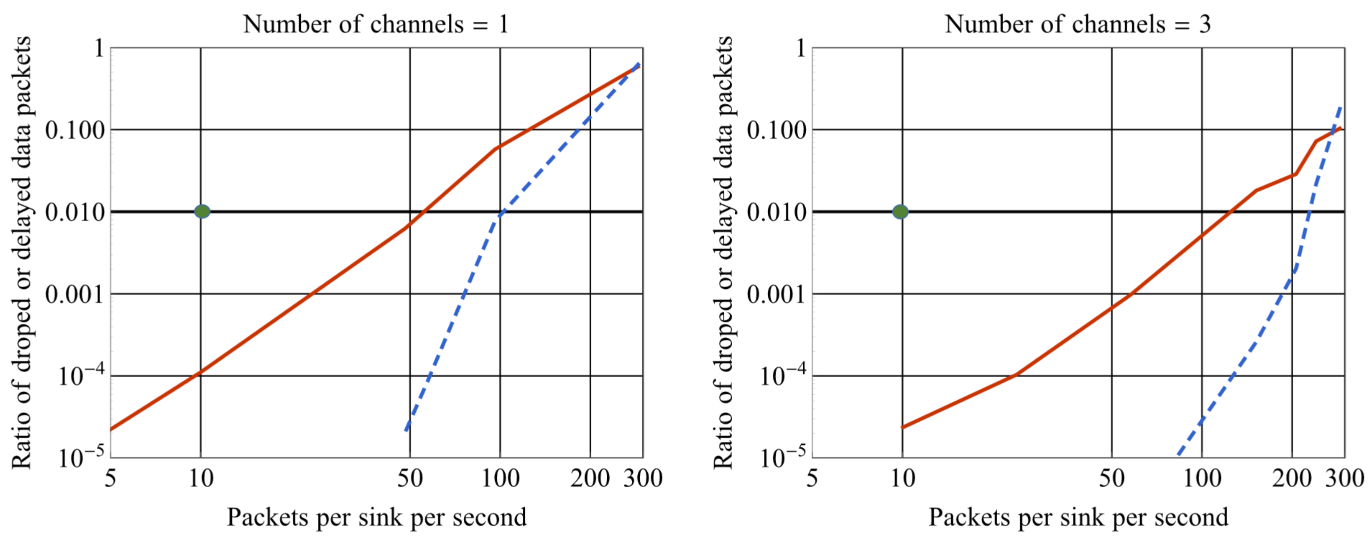


Figure 14: DECT configuration: Data Packet Drop ratio (end-to-end) (lost or delayed >10 seconds): Left side 1 channel, Right side 3 channels. Red line: 3 ARQ attempts, Blue line 8 ARQ attempts per hop (no combining)

Table 14: DECT configuration: Number of packets/second/sink or mean packet interval with 1 000 000 devices per km^2

	3 ARQ attempts	**8 ARQ attempts**
1 channel	56 pps or 1 message / 21.5 minutes/device	103 pps or 1 message / 11.6 minutes/device
3 channels	125 pps or 1 message / 9.6 minutes/device	228 pps or 1 message / 5.2 minutes/device

Discussion

As in both results the number of devices is kept as in ITU-R requirement, the 100 packets/second operating point means that each device is creating one packet in every 12 minutes instead of 120 minutes. These results indicate that system is able to deliver more frequent information on applications when needed without capacity issues. By using 3 operating channels (less than 5.2MHz of spectrum) with maximum of 3 ARQ attempts the system is able to deliver over 17 times more capacity than ITU-R required when system is deployed on 700 MHz. Indeed, based on results it is clear that changing the transmission band from 1900 MHz to 700 MHz and increasing the BS antenna height from 5m to 25m the system capacity is improved more than 20%.

99.9 percentile end to end delay performance

Results for ITU-R configuration

Figure 15 shows the results using 700 MHz band and 25 m antenna height for the end to end delay of 99.9 percentile, i.e. at this point only 0.1% of packet are dropped due to delay. Again, the green dot represents the ITU-R requirement of 10 second delay limit. Notable, when using 3 operating channels at 700MHz even 300 packets per second is not sufficient to exceed 10 second delay limit.

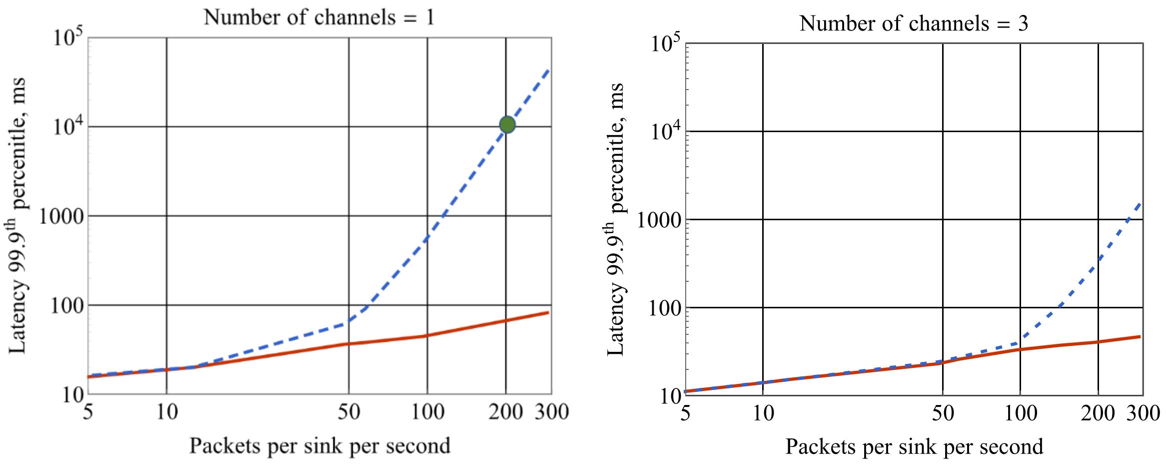


Figure 15: End to End Packet Delay of 99.9th percentile
Left side 1 channel Right side 3 channels.
Red line: 3 ARQ attempts, Blue line 8 ARQ attempts per hop (no combining)

Results for DECT configuration

In Figure 16 we show the end to end delay of 99.9 percentile, i.e. at this point only 0.1% of packet are dropped, using the DECT configuration. Again, the green dot represents the ITU-R requirement of 10 second delay limit.

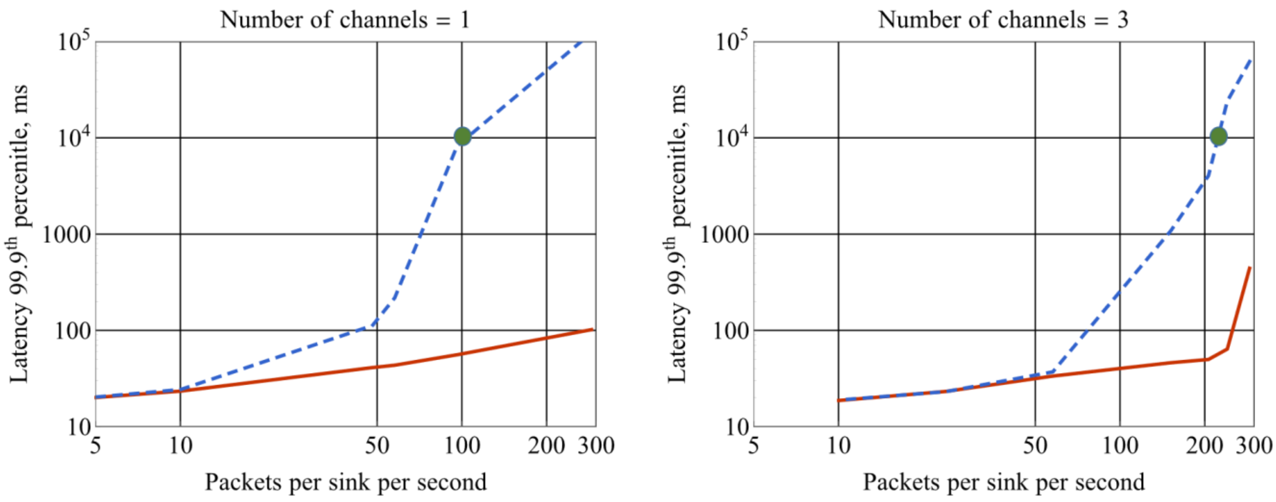


Figure 16: DECT configuration: End to End Packet Delay of 99.9th percentile
Left side 1 channel Right side 3 channels.
Red line: 3 ARQ attempts, Blue line 8 ARQ attempts per hop (no combining)

Discussion

It is notable that the end to end delay is never exceeding 10 seconds when only 3 ARQ attempts are allowed per hop when one or multiple channels (3 or more) are used. When high number of re-transmissions is allowed the delay starts to cumulate when the system starts to be overloaded. This overload point is around 105 pps and 222 pps (for 1 channel or 3 channels respectively) for 99.9 percentile performance point for the DECT configuration.

For WP5D configuration as the capacity is increased the delay of 99,9 percentile of the packets is reached at the level of 200 pps with single channel and when 8 re-transmissions is allowed. It is also notable when the system is not in overload situation, the system can provide below 100 ms end to end latency with very high reliability of 10^{-5}.

Conclusion 2: DECT-2020 using single 1.728 MHz channel can support ITU-R Connection density of 1 000 000 devices per km^2 with required data intensity.

Conclusion 3: In case of 3 channel used for mMTC system, the capacity is more than doubled compared single channel results.

Conclusion 4: Supported traffic intensity per device can be significantly higher as shown in Table 13. With single 1.728 MHz channel the 1 000 000 device density, each device can send packet in every 9.7 minutes. Alternatively, this capacity can be used for increasing the number of devices, when keeping the traffic intensity at ITU-R requirement level, or used for other services.

Conclusion 5: When using ITU-R scenario parameters, 700MHz as operating band and 25m as BS antenna height improves the system capacity more than 20% compared with the DECT scenario.

Annex B – Additional Information on URLLC scenario

B.1 U-plane latency evaluation

For low-latency systems, the DECT frame will be configured with alternating down-link / up-link slots. Low-latency transmissions use a high-efficiency packet “full slot” (slot width is 0.416 ms). Transmitter processing delay is 1 OFDM symbol (0.0416 ms). Receiver processing delay is 2 OFDM symbols (0.0832 ms).

Assuming “full-buffer” scenario, where data is always available for transmission (this is normal case for audio streaming or closed-loop control systems), then the U-plane latency is: 0.416 + 0.0416 + 0.0832 = 0.5408 ms.

U-plane latency calculation is identical for up-link and down-link cases.

When HARQ is used, the HARQ round-trip duration is 6 slots in worst case, i.e. 6 × 0.416 = 2.496 ms. If we assume HARQ BLER of 10%, then this will contribute 0.2496 ms to the average U-plane latency, i.e. when HARQ is used the average U-plane latency is: 0.5408 + 0.2496 = 0.7904 ms.

Table 15: U-plane latency

Step	Description	Value
1	Transmitter pre-processing delay	0.0416 ms
3	TTI for data packet transmission	0.416 ms
4	HARQ retransmission (6 slots round trip, assuming 10% BLER)	0.2496 ms
5	Receiver processing delay	0.0832 ms
	Total one way user plane latency	0.7904 ms

B.2 C-plane latency evaluation

A DECT-2020 PP potentially supports several different "battery efficient" states, e.g. powered-down, hibernating, low-duty cycle, etc. For the purpose of the study of the C-plane latency, the assumption is that the PP is locked to the FP, i.e. periodically receiving the FP's beacon transmission. In DECT terminology, this is "Idle Locked" state. The end-state is the start of "continuous data transfer". In DECT terminology, this is "Active Locked" state.

The process of transition from "Idle Locked" to "Active Locked" state requires the PP to send an "Access Request" message on an available Random Access Channel, and then receive an "Access Grant" message from the FP. The allocated resources can then be used at the first availability.

In an un-loaded system, we assume there is availability of Random Access Channels (and no contention with other users) and that there are resources available for the "continuous data transfer".

Table 16: Signalling delay from non-associated to associated

Component	Delay [ms]	Comment
Average association request TX resource waiting time	5	At least one resource in every 10ms frame. More frequent resources allocation is possible.
Association request TX message transmission	0.4167	Single slot transmission
Association request processing time	1 or 5	In DECT-2020 only installation DL slot for association response after 2 slots. When operating in legacy DECT compatible mode the response after 12 slots.
Association response TX response	0.4167	Single slot association response transmission.
Association response processing time	1	PP processing response.
Total	7.832 or 11.832	Total time depending on configuration. DECT-2020 only and DECT compatible.

Annex C: URLLC self evaluation details

C.1 Introduction

ITU-R has defined minimum reliability requirement to be $1-10^{-5}$ error probability for transmitting a layer 2 PDU (protocol data unit) of 32 bytes within 1 ms time limit and in channel quality at the coverage edge in the Urban Macro-URLLC test environment **Error! Reference source not found.**. In order to meet this delay requirement, single time slot transmission of DECT-2020 system is used.

In addition, ITU-R defines that the evaluation of the reliability is performed as combination of system level simulations and link level simulations as defined in **Error! Reference source not found.**.

" Step 1: Run downlink or uplink full buffer system-level simulations of candidate RITs/SRITs using the evaluation parameters of Urban Macro-URLLC test environment see § 8.4.1 below, and collect overall statistics for downlink or uplink SINR values, and construct CDF over these values.

Step 2: Use the CDF for the Urban Macro-URLLC test environment to save the respective 5th percentile downlink or uplink SINR value.

Step 3: Run corresponding link-level simulations for either NLOS or LOS channel conditions using the associated parameters in the Table 8-3 of this Report, to obtain success probability, which equals to (1-Pe), where Pe is the residual packet error ratio within maximum delay time as a function of SINR taking into account retransmission.

Step 4: The proposal fulfils the reliability requirement if at the 5th percentile downlink or uplink SINR value of Step 2 and within the required delay, the success probability derived in Step 3 is larger than or equal to the required success probability. It is sufficient to fulfil the requirement in either downlink or uplink, using either NLOS or LOS channel conditions."

For the URLLC self evaluation downlink full buffer system level simulation has been used.

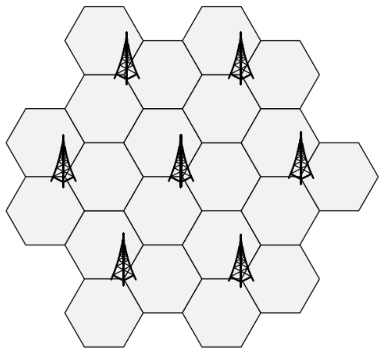
System Parameter

The URLLC system simulations are done in Urban Macro URLLC environment as shown in Figure 17 using either UMA_A or UMA_B channel model. The environment assumes high tower, and high transmission power macro-cellular base station network deployment with transmission powers up to 49 dBm for 20MHz bandwidth.

Figure 17: Layout of the environment

FIGURE 2

Sketch of hexagonal site layout



We have considered three URLLC system configuration which we see highly realistic.

- The first one a single 1.728 MHz channel is applied for URLLC service, i.e. system operates in a single frequency network.
- In the second scenario the URLLC system has 3 DECT-2020 channels and frequency reuse is arranged between neighbouring BS's.
- In the last scenario the URLLC system uses 7 channels out of 10 channels available at the 20 MHz band.

The setup of these three scenarios is presented in Figure 18, including the interfering sources to single reference cell.

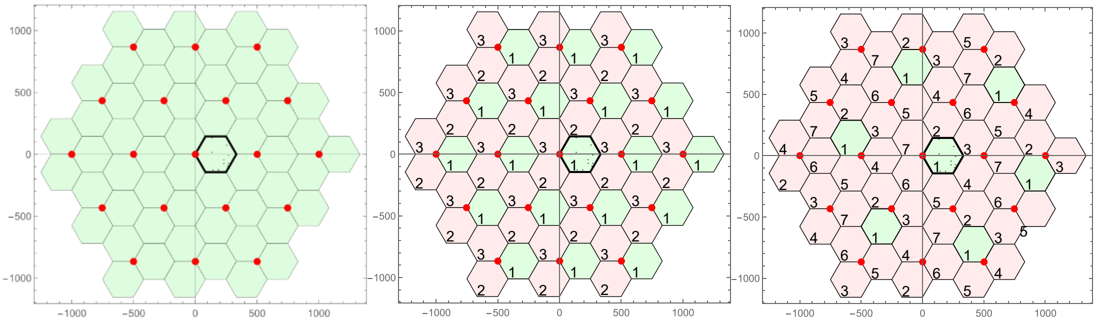


Figure 18: Evaluated URLLC system configuration. Green colour indicates interfering cell to single reference cell. Number indicates the used channel in a given configuration.

Table 17 presents the evaluation configuration parameters, we follow these parameters accurately, providing results with different DL TX power levels and antenna configuration in above system configurations.

Table 17: ITU-R evaluation parameters and DECT URLLC evaluation parameters.

Parameters	**Rep. ITU-R M.2412-0, Table 5) Urban Macro-URLLC test environments, configuration B**	**DECT-2020 URLLC evaluation**
Baseline evaluation configuration parameters		
System Architecture	Star with 19 sites, each site has 3 TRxPs (cells). Device connects directly to BS.	Star with 19 sites, each site has 3 TRxPs (cells). Device connects directly to BS.
Carrier frequency for evaluation	700MHz	700MHz
Channel model	Urban Macro	Urban Macro
BS antenna height	25m	25m
Total Tx Power per TRxP in BS/sink	49dBm for 20MHz	Results provided with 23dBm and 49dBm for 20MHz
UE/node power class	23	Not applicable as DL only
Percentage of high loss and low loss building type	100% low loss	100% low loss
Additional parameters for system-level simulation		

Inter-site distance	500m	500m,
Number of antenna elements per TxRP	Up to 64	Results provided with 20, (5x4), 60, (15x4) antenna elements.
UE antennas	Up to 4	4
Device deployment	80% indoor, 20% outdoor	80% indoor, 20% outdoor
Inter-site interference modelling	Explicitly modelled	Explicitly modelled
BS noise figure	5 dB	Not applicable – DL only
UE noise figure	7 dB	7 dB
BS/sink antenna element gain	8 dBi	8 dBi
UE antenna element gain	0 dBi	0 dBi
Thermal noise level	–174 dBm/Hz	-174 dBm/Hz
Traffic model	Full buffer	Full buffer
Physical layer packet size	Not defined	Not applicable but Single 32 byte can be packet mapped to long pre-ample packet modulated according MCS2 (QPSK ¾), in link simulations.
Simulation bandwidth	Up to 100 MHz	Results provided with single, three and 7 non-overlapping channels. Channel Bandwidth 1.728 MHz.
UE density	10 UEs per TRxP	10 UEs per TRxP
UE antenna height	1.5m	1.5m

System level simulation results

In the following figures we present the simulation results of the obtained SNR and SINR with different number of used of channels, TX power and different BS antenna configurations. The CDF of the SNR represent the signal to noise ratio when no inter cell interference is considered. It can be considered as baseline result showing that system is not noise limited, whereas the SNIR provides the result for ITU-R system evaluation. All figures include two lines, the horizontal line marks the 5th percentile portion of the devices and vertical line marks the 8.6 dB SINR level (Not 0dB level), which corresponds to SINR level for 10^{-5} BLER in link level simulations. The Table 18 provides the summary of these results.

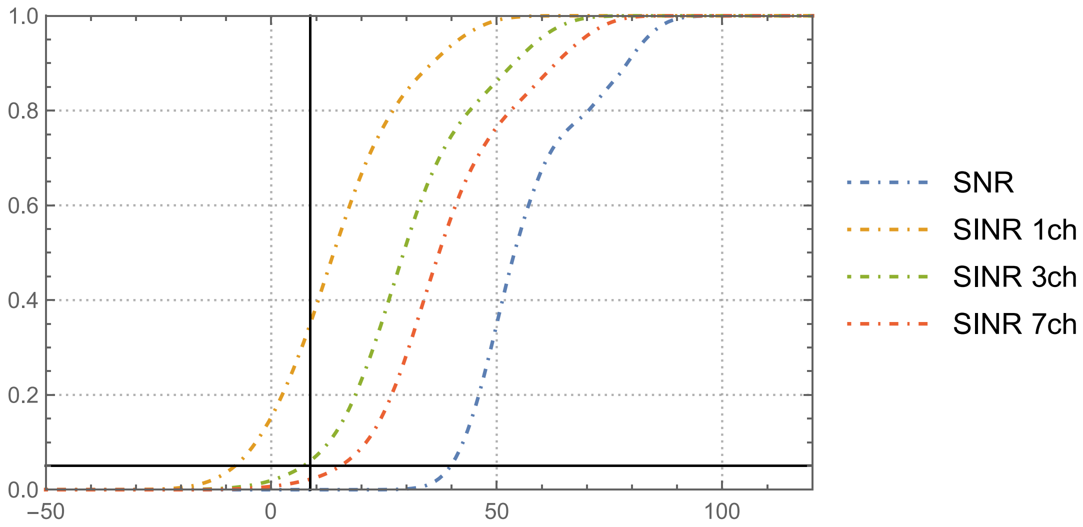


Figure 19: CDF of the SINR with Tx Power: 23 dBm, BS 5x4 Array

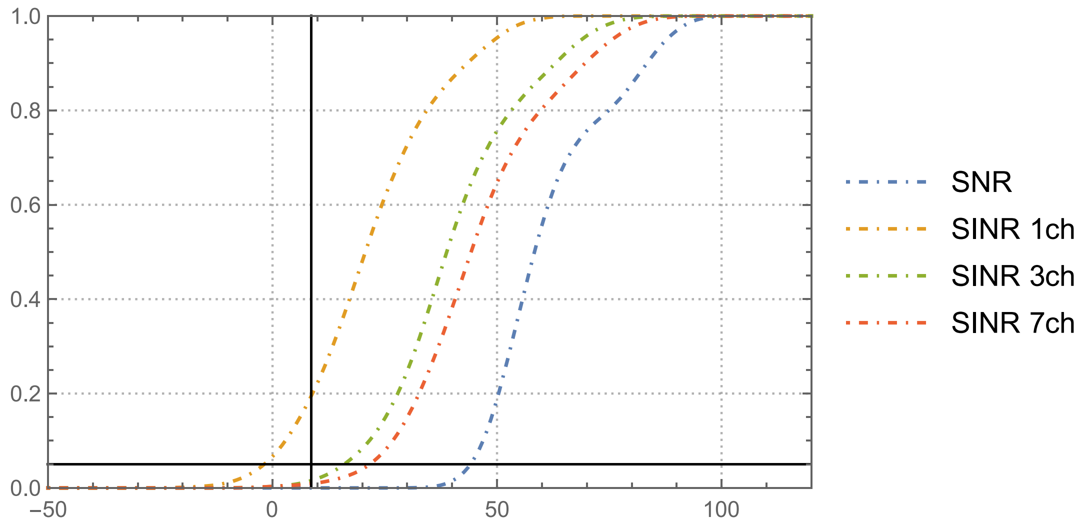


Figure 20: CDF of the SINR with Tx Power: 23 dBm, BS 15x4 Array

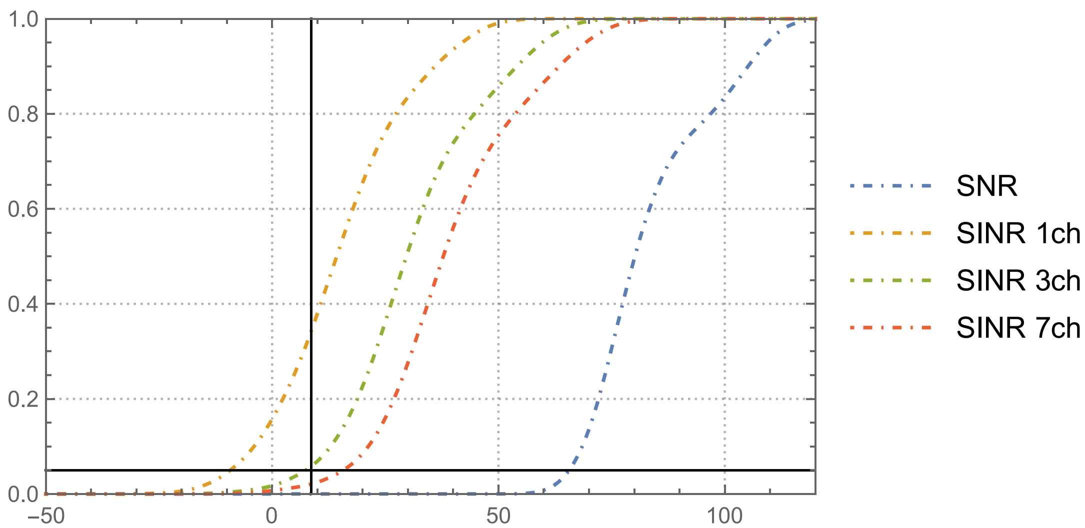


Figure 21: CDF of the SINR with Tx Power: 49 dBm, BS 5x4 Array

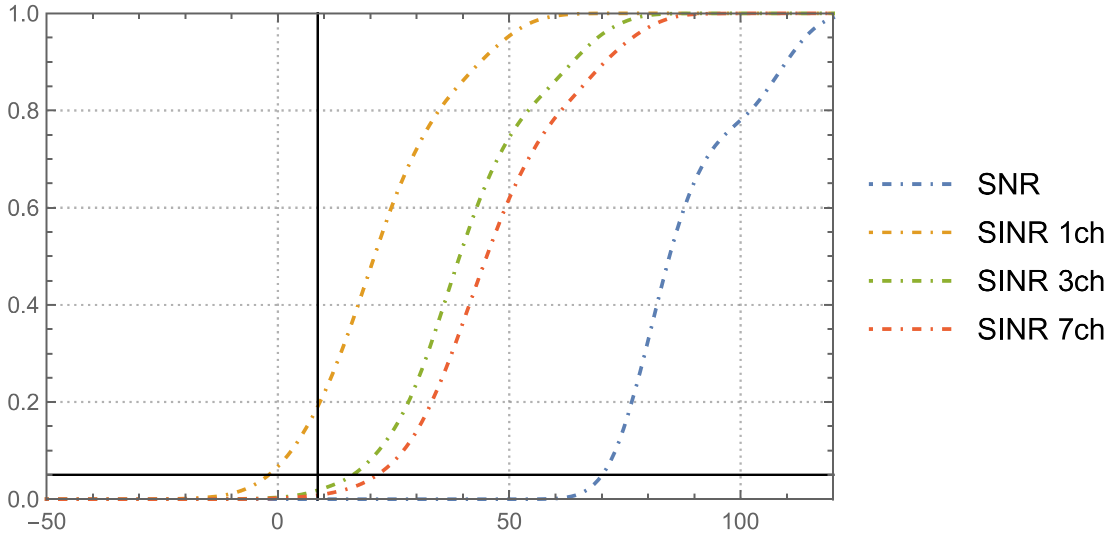


Figure 22: CDF of the SINR with Tx Power: 49 dBm, BS 15x4 Array

Table 18: Obtained SINR values in dB's at the 5 percentile point of the CDF

Number of used channels	23dBm Tx power, 5x4 antenna arrow (dB)	23dBm Tx power, 15x4 antenna arrow (dB)	49dBm Tx power, 5x4 antenna arrow (dB)	49dBm Tx power, 15x4 antenna arrow (dB)
1	-7.7	-1.5	-9.0	-1.7
3	7.2	16.1	7.6	16.6
7	15.5	22.0	16.2	21.6

Link level simulation results

Using DECT-2020 NR downlink/uplink single-stream configuration and BCC coding, the most reliable single-slot, 32 byte payload (as per IMT-2020 requirement for URLLC), long preamble packet corresponds to $W = W_{BC} = 1.728$ MHz with MCS2 (raw data rate: 1.872 Mbps). Such packet can carry up to 37 bytes over 4 available data field symbols.

From DECT-2020 NR link level simulation results the required SNR for 10^{-5} PER is approximately 8.6 dB (see Figure 23). It is noted that this value is 1.8 dB better than the SNR value for 1% PER.

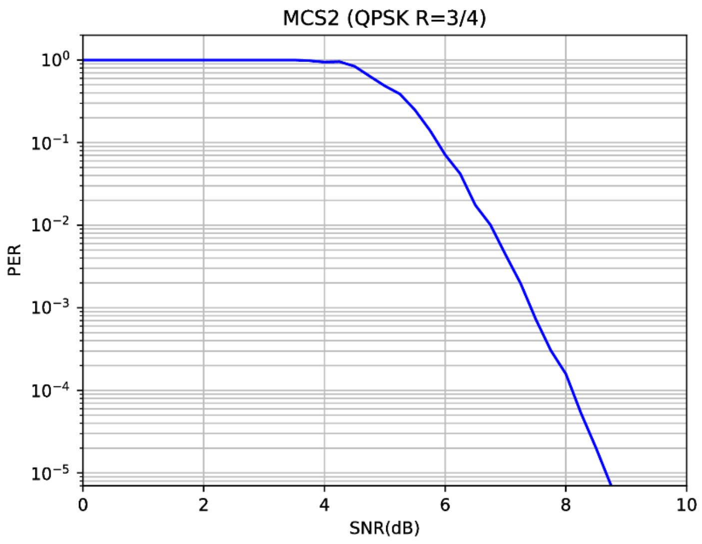


Figure 23: URLLC simulation

Conclusion

Based on Table 18 results, it can be noted that DECT-2020 can provide clearly higher SINR than 8.6 dB in ITU-R evaluation scenarios when appropriate system configuration is used. The link level simulations the SNIR level was providing the required 10^{-5} Block error rate. The evaluated configurations that provide much higher SINR were:

- Three or more operating channels with antenna configuration having 15 x 4 antenna elements
- Seven or more operating channels with antenna configuration having 5x4 antenna elements.

Additionally it can be seen that with antenna configuration 5x4 elements, the system less than 1.5 dB away from required SINR level.

From the system and link level simulations a cell area reliability of 95% for URLLC has been obtained.

Conclusion: DECT-2020 system can meet the URLLC service requirement in ITU-R Macro-URLLC evaluation environment.

Annex D – Additional Information on ‘Mobility interruption time’

D.1 Types of handover

D.1.1 Intra-System handover may be intra-cell or inter cell.

Intra-cell handover may be controlled by either the PP or the FP and triggered when quality on allocated carrier-slot-combinations becomes poor and other free carrier-slot-combinations exist. Detection of free carrier-slot-combinations is based on a spectrum sensing paradigm and takes into account the activity of other uncoordinated systems. Seamless handover is supported. The PP sends a handover-request to the FP on the selected random access channel. If the FP accepts the request, then it indicates the position of the new traffic channel and the data will be switched over. After that the old channel will be released.

Inter-cell handover is generally controlled by the PP and triggered when quality on allocated carrier-slot-combinations becomes poor and another suitable FP is becoming stronger. Seamless handover is supported. The PP sends a handover-request to the new FP on the selected random access channel. If the FP accepts the request, then it indicates the position of the new traffic channel and the data will be switched over. After that the old channel will be released.

D.1.2 Inter-System handover

Inter-System handover is performed in the same way as inter-cell handover. Seamless handover is supported. Both systems should be interconnected by the proper network infrastructure.

D.2 Interruption time

The handover procedure in DECT is seamless. If there is a need to change the radio link, then the best available new channel is selected to set-up a new link. For a short time the information is transmitted in parallel on the old as well on the new link. After the quality of the transmission on the new link has been confirmed, the old link will be released and the handover procedure has been completed. This seamless handover guarantees, that there is no interruption time for the transmitted user information.

Annex E – References

[1] Report ITU-R M.2410-0 Minimum requirements related to technical performance for IMT-2020 radio interface(s), (11/2017)

[2] Report ITU-R M.2412-0 Guidelines for evaluation of radio interface technologies for IMT-2020, (10/2017)

[3] 3GPP TS 23.501 “3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; System Architecture for the 5G System; Stage 2 (Release 16)”

[4] ETSI TR 103 514 “Digital Enhanced Cordless Telecommunications (DECT); DECT-2020 New Radio (NR) interface; Study on Physical (PHY) layer”