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FellowMe Cache: Fog Computing approach to enhance (QoE) in Internet of Vehicles

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ABSTRACT

Among metrics that highly affect video quality and quality of experience (QoE), we can cite the delay and cost transmission caused by mobile network overhead. Moreover, Information centric networking (ICN) is a new architecture that is proposed as a technique that offers very high throughput rates and very low latency, especially in QoE sensitive applications such as multimedia content delivery for the future communication networks. Indeed, unused memory in user equipment can be used to cache contents and afford it to the other nearby users on demand. This caching method is considered as one of the most promising solutions to enhance the QoE of users. On the other hand, one of the major research goals is to improve caching nodes decision based on nodes' characteristics. In this paper, we propose a new programmable architecture named FollowMeCache based on Software Defined Network (SDN), ICN approaches and Fog Computing for cache node selection using the Connected Dominating Sets (CDS) in order to reduce the download delay and cost for the users' requested video. In fact, we define cache node selection algorithm based on Influence factor to elect the appropriate nodes from the CDS set to build the cache. This metric takes into consideration the connectivity degree, Zone of Interest (ZI), node capacity, user preference and its location. In order to evaluate the proposed solution, we define a smart event use case. The performance evaluation is conducted by using network simulator and the obtained results show that our approach can give significant gain in terms of network throughput and the transmission delay.

1. Introduction

With the increasing growth of the Internet of things (IoT) [1], there will be tens of billions of connected devices. These connected devices will have sensing and intelligent capabilities for communication, collecting data and collaboration. As a typical example of IoT, we can cite Internet of Vehicle (IoV) [2,3] based on sharing ubiquitous information and content such as location tracking, remote monitoring…between vehicles with little or no human intervention. Device-to-device (D2D) communication [4] to deliver requested content without using the cellular network, can be considered as an attractive solution for future IoV networks. Vehicle to Vehicle communication (V2V) [5] and D2D can significantly offload network traffic and enhance its performance [6,7]. Indeed, V2V/D2D communications are a direct communication between two mobile vehicles without the use of a base station (BS) or a telecommunications network: The new features of mobile users today such as large storage capacity, computational power, long battery life, GPS location functions, as well as heterogeneous wireless interfaces such as WIFI, cellular, and Bluetooth… allow them to play a more active role in content distributions rather than simply being a passive device for consuming mobile data [8]. Therefore mobility [9,10] can help the nodes to improve the energy efficiency of the network.

On the other hand, there has been a new emerging trend in integrating ICN and SDN together in the future research field [11]. ICN [12] is a novel architecture that is proposed as a technique which has the potential to get a very high throughput rate and very low latency, especially in QoE sensitive applications such as multimedia content delivery for the future communication networks [13]. ICN is defined as a communication paradigm that aims to replace current IP networks [14]. In ICN, a node broadcasts its interest in content/information by using the name of this content. Each node in the network can respond, to this interest, if it has the requested content, which makes content

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independent of a specific node (address) in the network [15]. This is achieved by allowing nodes to store information when transferring information from the interests/responses between a source and a destination. Also, ICN has been proposed as a promising solution for IoT scenarios [1,15]. Besides, SDN separates the data and control planes and introduces flexible programmability to network equipment, which facilitates the design, management and administration of network services.

In this paper, we focus on the dissemination and data transmission in vehicular networks while reducing the communication cost in terms of overhead, energy and cellular traffic. This environment is possible via the vehicular heterogeneous networks where vehicles (devices) are equipped with both cellular and non cellular communication interfaces. In order to connect vehicles to Internet with minimum cellular traffic and cost. We present an hybrid and pro active architecture FollowMeCahce based on SDN and ICN approaches and CDS algorithm [16]. It is very important to propose an hybrid architecture to consider the different technologies' characteristics (licensed such as D2D communication in 5G, Machine-Type Communication (MTC) and unlicensed like IEEE802.11 (WiFi), IEEE802.15.1 (Bluetooth)...) and to ensure their coexistence. Besides, we rely on Fog Computing in our approach to be closer to the IoT devices/sensors and extends the Cloud-based computing, storage and networking facilities [17].

The main contribution of this work is as follow: mobile content objects will be carried by mobile devices and spread around to nearby interested consumers directly without engaging the cellular infrastructure in the data plane. In this case, mobile devices will be considered as an integral part of the mobile network with their own contribution of resources to serve other users. The advantage here is to effectively save the most expensive cellular spectrum resources via offloading to V2V based communications in support of content delivery. For that, in order to focus on the best choice of cache nodes and optimize network performance, we rely on FollowMeCache approach and we propose cache node selection algorithm (CNS) to create virtual Backbone (VB) [16,18] and select the most appropriate cache nodes based on influence factor metric. In other words, VB nodes distributed in the zone of interest ZI having a high degree of connectivity and high quality link with other mobile nodes, thus they have a high probability to be the cache nodes of our system.

The rest of the paper is organized as follows: we present a brief overview of the existing caching strategies in Section 2. In Section 3, we describe the proposed hybrid and programmable FollowMeCache architecture, its different modules and their interaction. In Section 4, we present the cache nodes selection mechanism used with the CDS algorithm, and the Influence Factor metric. In Section 5, we discuss and analyze the obtained simulation results to evaluate the performance of the proposed solution applied to an IoV use case. Finally, the conclusion is addressed in the last section. A schematic overview of the main body is provided in Fig. 1 to help understand the logic of the paper.

2. Related work

In this section, we present a brief overview of content caching selection mechanism defined in different works. In fact, we can distinguish two mechanisms for caching [19]: (i) with infrastructure caching assistance (Mobile Edge Computing (MEC), BSs…), (ii) without infrastructure caching assistance (select some end users as helpers for cache while considering some characteristics such as connectivity degree, available resources, link quality, etc.) to be even closer to the end user. Table 1 summarizes the different approaches used for caching purposes.

2.1. With infrastructure caching assistance

Hou et al. [20] propose in their work an optimized cooperative content caching architecture based on MEC servers. They perform caching in a collaborative manner to facilitate mobile content service. The MEC servers can share cached content via BS communications to further reduce the overhead by reducing the communication with the core infrastructure. In other work [21], Wi et al. investigate content caching in the heterogeneous vehicular networks HetVNet. They include Wi-Fi based Road Side Units (RSU), TVWS stations (TVWSSs), and cellular base stations (CBS)s, to significantly decrease transmission delay and offload cellular traffic. Authors in [22] propose heterogeneous network for video delivery which consists on one macro base station (MBS) and a set of small base stations (SBS)s. The caching content is stored in different SBSs considering the content popularity and the user preferences. [23] takes advantage of the transfer learning to predict content popularity. The most popular content is proactively cached in SBS until the storage in SBS is full. Unfortunately, this work presents a low caching efficiency because each SBS caches the most popular content independently. The same content is more likely to be cached by multiple SBSs. Authors in [24] address green and mobility-aware caching issues in 5G networks. They studied the influence of mobility on caching the content on SBS and mobile devices, and proposed a mobility-sensitive content placement model to enhance the success rate of caching. In [25], a femto-caching scheme is proposed for a cellular network combined with SBS. The content placement in SBS is centrally optimized to minimize the expected downloading time for files in order to enhance the network performance.

2.2. Without infrastructure caching assistance

Today, Device to Device D2D communications enable communication between mobile devices directly without passing through the cellular network (MEC, BS…). Meanwhile, novel technologies for mobile devices are characterized by long battery life, accurate GPS functions and large storage capacity.… These features allow mobile devices to be more active rather than simply being a dummy device for consuming data. For this, Chandrasekaran et al. [8] propose to use certain mobile nodes as data carriers (called helpers) and use these nodes as mobile caches strictly controlled by the BS. The BS uses an offline method to select the helpers based on their mobility profiles (active users who spend the longest time in a Point of interest (POI)). This method was proved to have less access delay, energy consumption and overhead ratio.

Authors in [26] address the problem of collaborative video caching in mobile ad-hoc networks. A virtual backbone caching nodes (VBC) will be elected based on the selection of available nodes considering its locations and resources capabilities (cache memory, node degree, link failure frequency). Besides, they define a virtual access point (VAP) set as a part of VBC that serves one or more of its clients' neighbors to further minimize the delay and transmission cost. In other work [27], authors propose an approach for selecting mobile nodes in order to partially cache highly requested files that must meet the minimum QoS requirement defined by the service provider. To do this, the authors define three main parameters: (1) Power capability score which considers the residual energy of the node and its expected transmission energy consumption used when transmitting data to neighboring nodes, (2) Mobility issues where only nodes having a high probability to be available in the communication distance of other mobile nodes at a later time are selected and (3) node flow time that considers the number of mobile nodes near the cache node requesting data, the time spent storing or updating the data and the access time for each mobile node nearby.

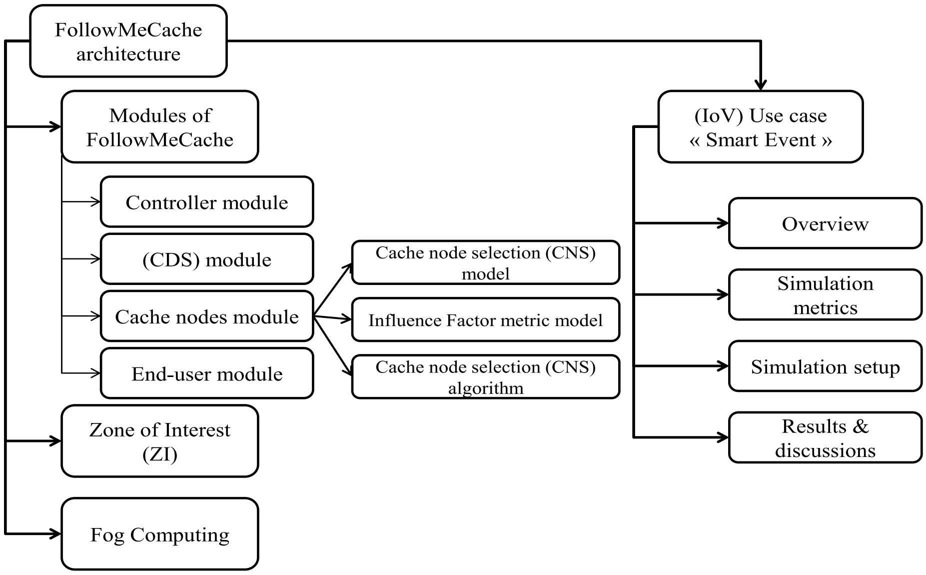

Fig. 1. FollowMeCache architecture overview.

In [28], the selection of cache nodes is based on the influence factor W (file similarity relationships between all nodes). For each node, one calculated W with all the nodes in its communication range. Nodes having a higher W are elected as caching nodes. Finally, Zhou et al. [29] propose a generalized dominating set (GDSC) approach for the content caching in Ad Hoc networks. This method is based on dominated set (DS) algorithm [30]. The GDSC is composed of the dominating nodes having the maximum m-hop neighbors in the network.

Despite the significant amount of research involved in cache node selection and caching model architectures, the proposed approach in this paper goes beyond existing approaches to provide hybrid and pro active architecture. The presented framework allows for the selection of the most appropriate cache nodes based on user preference, zone of interest ZI, DS and Link quality, which in turn are used to improve the QoE and network performance.

3. FollowMeCache architecture

In this section we detail the proposed hybrid and pro active architecture based on ICN paradigm, SDN and CDS approaches. FollowMeCache approach drives Internet traffic evolution to support higher QoE and performance networks upon an heterogeneous network. It combines the benefits of both ICN and SDN paradigms [31]. ICN/SDN is a new trend of future Internet research field, which leverages the benefits of SDN in efficient programmability and flexible manageability to support information centric networking [11]. In fact, future Internet paradigms recentering communication about content, such as ICN, seem like hopeful candidates to alleviate the challenges of an efficient and cost-effective video delivery by including multimedia content at network layer. Indeed, the ICN paradigm forms the future Internet architecture that has countered the data itself rather than its locations in the network [14]. It is a transition from a host-centric communication model to a content-centric system based on unique, location-independent content names, network caching and name-based routing [32]. In ICN, networking nodes cache the passing data chunk in its memory and afford it to the comparable request from its cache in the next request for the same data [33,34], mobile devices can use a part of its storage memory. Besides, the use of SDN paradigm allows us to benefit from its advantages: the separation between control and data plan, and the network becomes easier in term of configuration and deployment. The control plan corresponds to the brain of the network. It allows a dynamic management of resources, admission control, routing and forwarding data...

In this section, we detail the proposed FollowMeCache architecture and we define the concept of ZI and the utility of Fog Computing in our solution.

3.1. System design

Fig. 2 illustrates an overview of the proposed architecture which is divided in four modules:

3.1.1. Control module

We use the SDN controller to build the control module for our architecture [18]. It has key role in the network which has a global vision of the network architecture/topology and different network parameters. The main roles of the controller are as follows: coordination of the other modules, network configuration, resources management, construction of the CDS, selection of the cache node(s) from the CDS (based on cache node selection described in the next section) and finally decision making for the content caching based on ZI and user preference. Fig. 3 shows a schematic overview of the roles of SDN controller to have the best choice of cache nodes.

3.1.2. Virtual Backbone formation using CDS module

The CDS or VB is a part of the graph theory. The CDS is a set of nodes that are connected and dominating others. In literature, there are diverse multi-phase or single-phase algorithms [16,29,30,35,36]. In this paper we will rely on the CDS algorithm [16] since it takes into account the ZI concept and calculates the coverage area of each node in order to select the CDS.

This algorithm is based on four phases where the first two phases are applied to each subgraph that represents either inside or outside ZI. The last two phases are applied to the wireless network:

1. Compute the Maximal Independent Set (MIS) where no two nodes are adjacent, all nodes in MIS are colored red and others are colored gray.

Table 1
Caching solutions in the literature.

Ref.	Architecture	Cache nodes	Parameters used for the cache node selection
[20]	distributed	MEC servers	–
[21]	distributed	CBSs, TVWSS, RSU	caching capabilities of Wi-Fi based RSUs and TVWSSs
[22]	centralized	MBS, SBSs	caching capacity of each SBS
[23]	distributed	SBSs	–
[24]	distributed	SBSs, mobile devices	user mobility
[25]	distributed	SBSs	capacity storage
[8]	centralized: BS	mobile nodes	Zone of Interest, mobility profile
[26]	distributed	end-user device	resources capabilities (cache memory, node degree, link failure frequency)
[27]	–	mobile nodes	Power capability, mobility issue, node flow time
[28]	distributed	end user node	Influence factor based on content similarity
[29]	centric Adhoc network	the helpers are the dominating nodes in the network based on the GDSC algorithm	dominating set approach "GDSC"

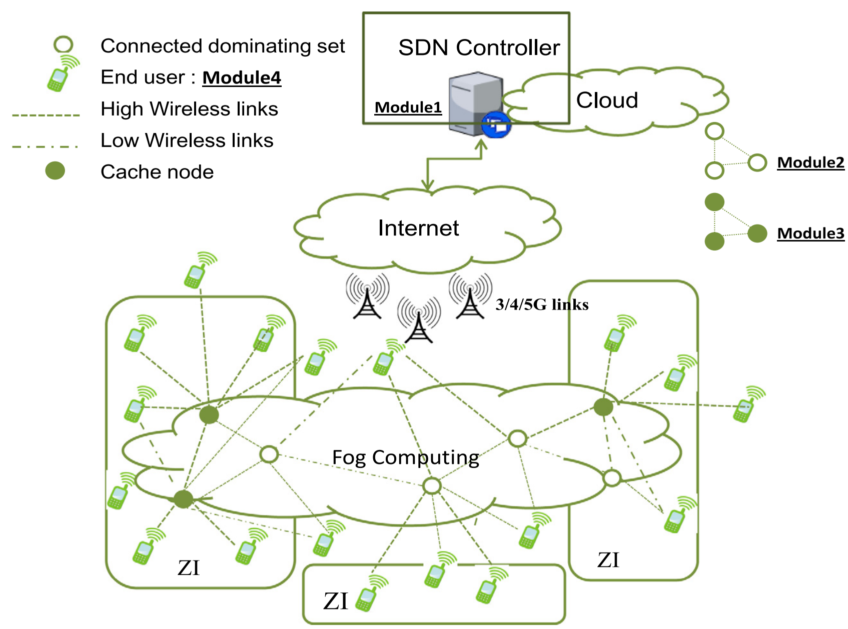

Fig. 2. FollowMeCache architecture.

2. Calculate the weight and score of each node where the score is expressed as the overlapping area ratio between the coverage area of the node and its corresponding zone of interest. The nodes having the highest score are selected as dominants and are colored black and their neighbors are colored white.
3. This step is divided into three parts:
   (a) Black nodes of a ZI must dominate neighboring gray nodes of an adjacent ZI by coloring them white.
   (b) The goal is to dominate all remaining gray nodes by black nodes. After this part all nodes become black (dominant nodes) and white.
   (c) Coloring remaining red nodes black if they have one hop from a black neighbor.
4. Black nodes are connected to create the CDS.

The CDS must be equipped with cellular communication (5G) to communicate with the SDN controller and non-cellular interfaces (wifi/802.11) to communicate with end users. The nodes in CDS are greeted by Fog Computing to make services close to end user devices in order to reduce the transmission cost and delay and ensure network scalability.

3.1.3. Cache node(s) module

In order to reduce the transmission cost and delay, the video content must be directly served to nearby interested clients without involving the cellular infrastructure in the data plane. In this case, mobile nodes selected to make the cache content must be dominating nodes belonging to CDS according to the ZI (i.e. those nodes are characterized by a high connectivity degree in the induced ZI based on the number of connected nodes demanding video requests with a high Link Quality Index (LQI)). The selection of cache nodes is carried by SDN controller based on the algorithm 1 detailed in the next section.

3.1.4. End user module

In the case of proposed architecture, the end user is a mobile vehicle who is interested in video streaming service. The communication between end the mobile end user and the Internet

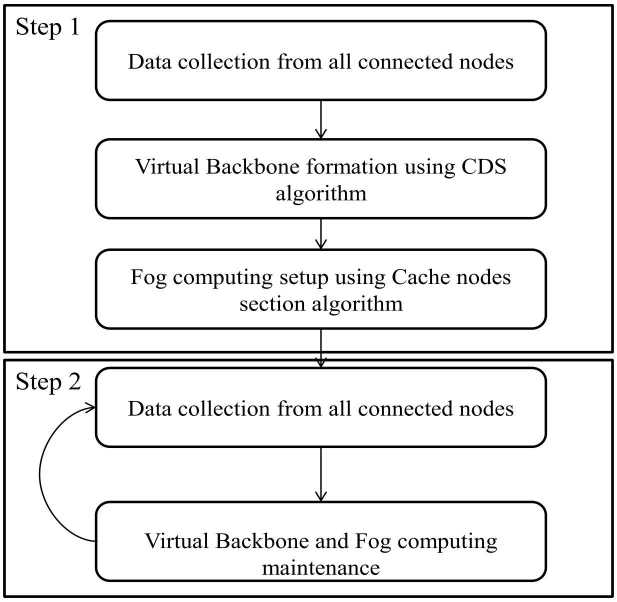

Fig. 3. Schematic Overview of SDN controller's roles.

is established via CDS through non-cellular communication. Each vehicle transmits to the SDN controller via 3G/4G/5G connection its own location coordinates and includes its list of known neighbors with their location.

3.2. Zone of interest ZI

The authors in [37] show that user interest in media content have important impact on its locality (i.e. people close to each other geographically may have similar interest). The concept of ZI allows us to better specify the popular content requested by customers in the ZI. For example, in geographical area where the Olympic Games are held, the popular contents having a high probability of being requested are the sequences related to this event. In this case, the cache nodes must be located in the heart of the event and hide the best sequences of it.

3.3. Fog computing

The fog computing is considered as an extension of Cloud Computing from the core network to the edge nodes [17]. The fog computing is hosted at the edge nodes with the SDN controller for the purpose of making services close to the end-users. It is considered today as the best candidate to make services more reliable and efficient.

4. Cache node selection CNS algorithm

In this section, we focus on the cache nodes construction. As described above, the optimal choice of cache nodes is very important in order to offload the content source. We model the factor influence metric that helps in the construction of cache nodes. In addition, we present the used algorithm which models the different steps to select the cache nodes.

4.1. The Cache node selection CNS model

We consider a realistic model for video delivery with mobile users (vehicles) located in/around the ZI k. Each user can play a role as requester or helper (cache node). We build the CDS set $S = \{s_1, s_2 \dots s_n\}$ from the existing users based upon the CDS algorithm described above. In addition, we denote $D_{(s)}$ as the set of nodes which are directly connected to the node s. We consider $C = \{c_1, c_2 \dots c_m\}$ where $(m < n)$ as the cache node set of our model where each user can request its desired content from the nearest node $(c \in C)$. In fact, the selection of node c is based on two conditions:

- The node s must be located in k.
- The node s must have the highest influence factor metric I.

In the next subsections, we detail the influence factor metric model and the CNS algorithm.

4.2. Influence factor metric model

The factor influence metric measures the connectivity degree based on the weight of nodes demanding video content with high LQI belonging to the same ZI. The LQI or Received Signal Strength Indicator (RSSI) is the estimation of the received signal power in the channel [38]. It has a fundamental impact on the network performance that is why it is necessary to be considered in the cache node selection. Eq. (1) shows how to calculate the influence factor:

$$W_s^k(i) = \rho_i \frac{LQI_{s,i}}{LQI_{th}}((1 - \varphi_i^k)\alpha + \varphi_i^k \beta) \tag{1}$$

Where:

K is an interest zone ZI, φ_i^k is a boolean metric where $\varphi_i^k = 0$ indicates that the node i belongs to the ZI k else $\varphi_i^k = 1$, α and β are weight factors such that $1 > \alpha > \beta$, α is assigned to the node belonging to k else we assign it the factor β. LQI_{th} is the threshold link quality defined in the environment between two nodes to receive a good video quality (acceptable QoE) and $LQI_{s,i}$ is the LQI between node s and i. Finally ρ_i represents the user preference metric.

In our work, user preference is introduced to observe demand on requesting video for user i. Our user preference model is based on learning requests from a user in the past to predict the content type currently requested. To facilitate this computation, we rely on Machine Learning process [39]. We run the Random Forest algorithm [40] each time to measure the user preference.

4.3. The Cache node selection CNS algorithm

The complexity of the proposed algorithm is $O(n^2)$. The construction of cache nodes is modeled into three steps (algorithm 1): Firstly we calculate the sum of the influence factors of each node s; $I_s = \sum_{i \in D(s)} W_s^k(i)$ where $D(s)$ denotes the dominant nodes connected to s. Secondly, to find the first cache node, we sort S in descending order according to I (.i.e. $S = \{s_1, s_2 \dots s_n\}$ where $I_{s1} > I_{s2} .. > I_{sn}$); the first node in S will be the first cache node, so we add it to C (i.e. $C = \{s_1\}$). Finally, if the set C is connecting to multiple nodes requesting different video contents at the same time that can overload the network and decrease the available bandwidth, that degrade the QoS between the cache node set C and its dominant nodes (i.e. to guarantee a better QoE client side). One must add a new cache node. In other words, while LQI around C LQI_c is less than the minimum LQI (i.e. σ) for well received the video content requested in acceptable network conditions, we must add a new cache node from CDS as indicated in algorithm 1. A flow chart is proposed as a heuristic to find the location of the cache (Fig. 4).

Input : S: Connected Dominated Set, LQI_{th}: Link quality threshold
$\varphi_s^k = 0$: s exists in the ZI k.
$D_(s)$: set of connected nodes to s.
σ : minimum LQI
Output: C: cache node set
Step1:
foreach ($s \in S$) && ($\varphi_s^k = 0$) **do**
  foreach ($i \in D_{(s)}$) **do**
    Calculate $W_s^k(i) = \rho_i \frac{LQI_{s-i}}{LQI_{th}}((1-\varphi_i^k)\alpha + \varphi_i^k\beta)$;
  end
  Calculate $I_s = \sum_{i \in D_{(s)}} W_i^k(i)$;
end
Step2:
Sort S in descending order according to I.
Add the first node from S to C i.e $C = \{s_1\}$
Step3:
while $LQI_c \leq \sigma$ **do**
  $j = j + 1$;
  Adding to C the node s_{j+1} from S;
end

Algorithm 1: Cache node selection CNS algorithm

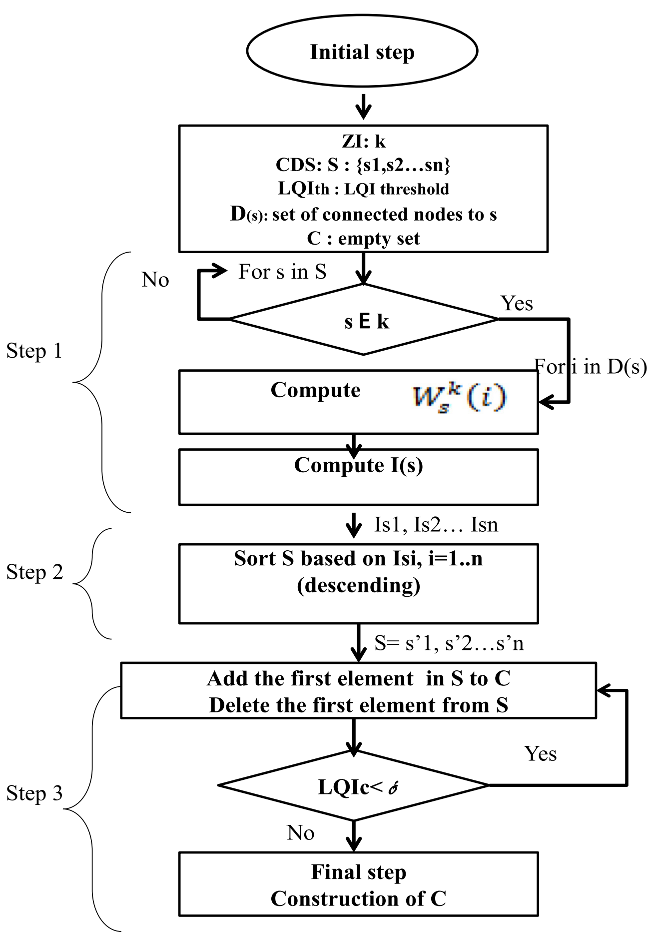

Fig. 4. FlowChart of the CNS process execution.

4.4. CNS and CDS reconstruction

The end user module in the proposed architecture is based on mobile vehicles where they can change their location at any time (node that arrives or leaves the ZI) which can cause a change in CDS and the influence factor value of some dominating nodes.

If we will recalculate CDS and CNS algorithms periodically, we will increase the complexity time and cost. For this, the flow chart in Fig. 5 highlights the cases when we must rebuild the CDS, CNS or both. We remark that if a dominant node goes out, we must recall the CDS algorithm to obtain new CDS set, after that we recalculate CNS algorithm. Also we need to recalculate the 2 algorithms when the SDN controller detects the arrival of a new node belonging to the ZI which affects the old dominating set and the influence factor of some nodes. Finally, if a CDS node leaves the ZI or node arrives in the ZI, SDN controller must reflate CDS and CNS algorithms. If a node arrives but does not enter in the ZI and has cache node neighbor, SDN controller will just recalculate the CNS algorithm.

In addition, topology change detection is done by the SDN controller via "discovery packet". In fact, each CDS node periodically sends a "discovery packet" which contains its current location and list of known neighbors with their locations to SDN controller via cellular interfaces (3/4/5G). So, by comparing the current and previous topology, the SDN controller can detect the changes and reconstruct the small CDS and cache node set. After that, each node is informed of its role (cache node or relayed node) and configuration using OpenFlow protocol.

5. Performance evaluation

We evaluate the proposed solution with IoT/IoV on the top of ICN and Named Data Networking (NDN) [41,42]. In fact, NDN is one of the most active ICN implementations and have been considered as promising communication paradigm for IoV [43].

Applying NDN in IoV context has several advantages: It well matches the vehicular applications context, which privileges the information to collect instead of the identity of the information provider [44]. So, NDN can support a massive amount of information which can be exchanged between vehicles and roadside units [42]. Besides, NDN is considered today as a novel technique which has potential to get a very high caching capability in IoV context [45]. For example authors in [46] propose an efficient content popularity-diversity replacement policy in Vehicular Named Data Network (VNDN) context based on NDN capability that aims to select the content with the highest popularity-density to be cached and the lowest density to be evicted due to the limitations of the cache store in VNDN. In other work [47], authors propose a novel proactive caching design based on mobility prediction scheme. The aim of this work is to predict the next RSU of a vehicle where the required content of interest to that vehicle will be cached. However, the proposed solution does not consider the V2V communication.

In Fig. 6, we describe a smart event use case as an IoV use case. The popular contents here having a high probability of being requested are video sequences related to this event. The mobile vehicles in the parking or around the mall can request at any time video sequences concerning this event. The ZI here is the mall and its parking. Each vehicle performs neighbor discovery/recovery by using periodic packets via V2V communications that are exchanged through IEEE 802.11p interfaces to learn and collect information about all neighbors and their respective locations and sends a "discovery packet" which contains its current location and list of known neighbors with their locations to SDN controller via cellular interfaces (3/4/5G). After that, SDN controller takes care of the rest: determining the cache nodes and the CDS and CNS reconstruction. In the next subsection, we present the performance evaluation and discuss the obtained results.

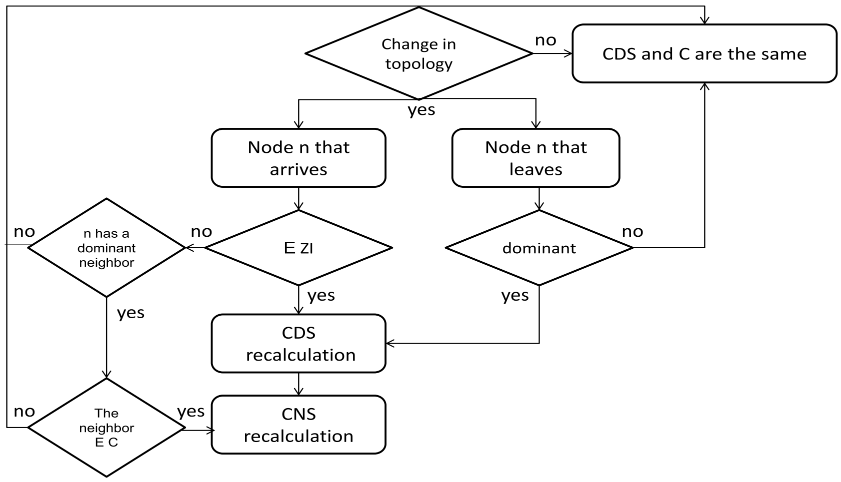

Fig. 5. FlowChart of CDS and CNS recalculation.

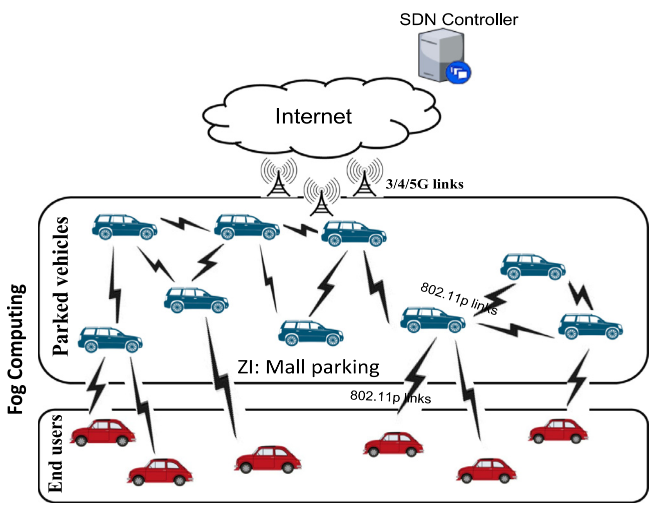

Fig. 6. Internet of vehicles architecture in the case of smart events.

5.1. Evaluation metrics

The objectives of caching are to enhance the user satisfaction QoE by increasing the network performance. For that, we define our evaluation metrics for this work by [48]:

- *End to end delay*: is composed of: end-point application delay and network delay. It is the time needed for the destination application to get the packet requested. A low value of end to end delay denotes a high QoE.

$$end\ to\ end\ delay = T_s - T_c \tag{2}$$

  Where T_s is the current simulation time and T_c is defined as the creation time of packet.
- *Network throughput*: defines otherwise the network performance, low value of throughput indicates a bad QoE. It is affected by the network congestion, end to end delay, packetloss rate ... Eq. (3) details the computation of throughput rate:

$$throughput = R_{WIN}/RTT \tag{3}$$

  Where R_{WIN} is the Receive Window and RTT is the round-trip time for the path.
- *Offloaded content metric*: is the ratio of content requests served via cache nodes (N_c) against the total number of requests made by all clients (N_T). High ratio means a better performance.

$$Offloaded\ Content = N_c/N_T \tag{4}$$

- *Overhead Ratio*: means how many redundant packets are transmitted to deliver one packet.

$$Overhead\ Ratio = N_{PT} - N_{PD}/N_{PD} \tag{5}$$

  Where N_{PT} is the number of transferred packets and N_{PD} is the number of delivered packets.

5.2. Simulation setup

We have implemented our architecture in Omnet++ [49] and INET [50] frameworks. In order to maintain clarity, this paper makes the following assumptions:

- The user preference for each user is the probability that the user *i* is interested in the videos of this event. It is measured by the Random Forest algorithm using Weka tool [51].
- To simplify the simulation, the VB is a static set, end-user nodes use the "VehicleMobility" as mobility model [50] and each node is assigned a unique identifying number.
- The SDN controller communicates with the CDS via (3/4/5G) interfaces. The CDS module communicates with end user module through WIFI interfaces.
- We apply the CNS algorithm to calculate the influence factor for each CDS node and determine the relevant cache nodes.
- We also set α and β weight factors to be 0.7 and 0.4 respectively.

After that, we compare our approach "Follow Me Cache" where the important content is cached in the cache nodes selected by our algorithm, with different scenarios: (Scenario 1) demanding requests from the network infrastructure, (Scenario 2) the controller module selects the cache nodes randomly from the ZI and (Scenario 3) the controller module selects the cache nodes randomly outside the ZI. The detailed discussions and simulation parameters are summarized in Table 2.

Discussion 1: In this discussion, we carried out between the FellowMeCache approach and others scenarios to evaluate the End-to-end delay metric. For this simulation, we fixed the density of end users to 30, the coverage area of ZI to 2000 m^2. The number of cache nodes is measured by the CDS and CNS algorithms for

Table 2
Simulation parameters.

Discussion	Number of end-users	Coverage area of ZI	Number of cache nodes
Discussion 1	30	2000 m^2	5: for scenario 1,2,3/Calculated by CDS and cache node selection algos for FollowMeCache approach
Discussion 2	10 to 50	2000 m^2	5: for scenario 1,2,3/Calculated by CDS and cache node selection algos for FollowMeCache approach
Discussion 3	80	1600 m^2 to 4200 m^2	5: for scenario 1,2,3/Calculated by CDS and cache node selection algos for FollowMeCache approach
Discussion 4	80	2000 m^2	3 to 20

the FollowMeCache approach and it is fixed to 5 for the other scenarios.

Discussion 2: In this discussion, we evaluate the network throughput rate relative to the density of end users in the network. For this, we used the same network configuration as introduced in the scenario 1 but we vary the number of users from 10 to 50.

Discussion 3: In this case of discussion simulation, the network configuration is fixed with number of nodes equal to 80 nodes and varied the ZI coverage area from 1600 m^2 to 4200 m^2 radio range from 10 to 18. The number of cache nodes is measured by the CDS and CNS algorithms for the FollowMeCache approach and it is fixed to 5 for the other scenarios. In this discussion, we evaluate the effect of the ZI coverage area on the network throughput rate.

Discussion 4: We evaluate in the last discussion, the effect of the number of cache nodes on the network performance (network throughput) based on scenario 2 and 3. In fact, in the FollowMeCache, the cache nodes are elected by CNS algorithm based on different parameters. To do this, we used the fixed number of nodes with 80, ZI coverage area with 2000 m^2, and we varied the cache nodes from 3 to 20.

5.3. Results and discussions

Impact on end to end delay: Fig. 7 illustrates the comparison between our approach FollowMeCache and the other scenarios detailed in the previous subsection. It shows that the end-to-end delay is very important when the video is requested from the core network and starts to decrease when the content is more closer to the concerned node (the end-to-end delay decreases from 5,76E−03 ms to 2.66E−03 ms). We remark also that with the FollowMeCache method, when obtain the minimum of end-to-end delay (1.02E−03 ms), so the maximum of QoE. This is due to the impact of LQI, ZI and user preference.

Impact on the throughput with different number of end_user: Fig. 8 shows the variation of the throughput rate behavior when increasing the user density while keeping the same coverage area of ZI. We note here that we study the network scalability and not the network density. The following curve indicates that the network performance decreases with the increasing of node density in the network but the FollowMeCache approach takes always the highest throughput (from 0.3 to 0.41). On the other hand, the throughput rate is always low using the scenario 1 and 3 (< 0.22) and higher with the FollowMeCache and scenario 2 due to the consideration of ZI but the FollowMeCache outperforms scenario 2. For this reason, the ZI is not sufficient for a better selection of cache nodes, it is necessary to consider the LQI between cache nodes and end-user nodes and user preference.

Impact on throughput with different size of ZI : Fig. 9 depicts the effect of the ZI coverage area on the network performance modeled by the throughput rate. The throughput rate increases with the ZI coverage area and reaches 0.46 with the FollowMeCache approach that outperforms other scenarios. This can be explained by the fact that when the ZI area increases, the ZI will accommodate more users interested by the event so more content requests. We can note also that the network performance remains very low with the increase of ZI when we request the core network (0.2). In other words, the ZI has no effect on network performance when demanding requests from the core network. Besides, if we take into account the ZI in the cache node selection (scenario 2 and 3), we can improve the throughput rate from 0.24 to 0.36. In contrast, if we consider the LQI, user preference and the area of ZI, we can reach high throughput (> 0.45). Thus, we can conclude that for the best selection of cache nodes, we must take into account the LQI, user preference, the area of ZI.

Impact on throughput vs number of cache nodes: Fig. 10 presents the evolution of throughput rate when increasing the number of cache nodes in scenario 2 and 3. As shown, the throughput rate is important but decreases every time we add cache nodes from 0.7 to 0.5. On the other hand, we note that scenario 2 outperforms scenario 3. Indeed scenario 2 has the advantage of working inside ZI area. We can conclude that the network performance is better when one optimizes the cache node set. In other words, one must select the minimum cache nodes because when we add more cache node, we need more memory, more transmission cost, energy and packet exchanged between the added node and the controller which decrease the network performance.

Furthermore, the caching performance of the proposed FollowMeCache is compared to the existing caching strategies: Cache on the Move [8] and Greedy algorithm [52]. We note that in Cache on the Move scheme, the selection of cache nodes is based on ZI and mobility profile (time spent in ZI). On the other side, in our scheme, we are based on ZI, LQI, user preference and mobility profile. The percentage of offloaded content is the performance metric considered in this phase. We simulated this network with 200 nodes and the area of ZI was 5000 m^2. In Fig. 11, we plot the percentage of offloaded content over time. The curves follow increasing stage and steady stage. In the increasing stage, the offloaded requests ratio keeps rising in different approaches, with increasing numbers of content being cached at cache nodes. In other words, we tend to find the right popular contents in cache nodes memories (before being full). On the other hand, in steady stage, all the cached memories of cache nodes are saturated with maximum contents. Besides, as observed, Greedy algorithm achieves similar performance compared to our approach which outperforms Cache on the Move approach with an average of 10%.

Fig. 12 evaluates the variation of offloaded content when increasing the ZI area. We can see that while offloaded content remains stable using greedy algorithm, our FollowMeCache algorithm achieves better performance when the size of ZI areas increases compared to Cache on the Move algorithm. For greedy algorithm, ZI areas have no impact on CDS size [16] and Cache nodes selection, so the offloaded content will not be affected by ZI

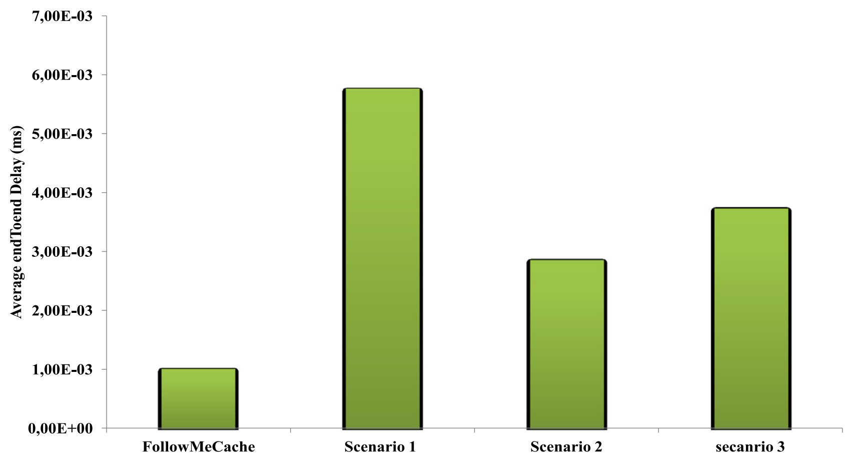

Fig. 7. End to end Delay analysis.

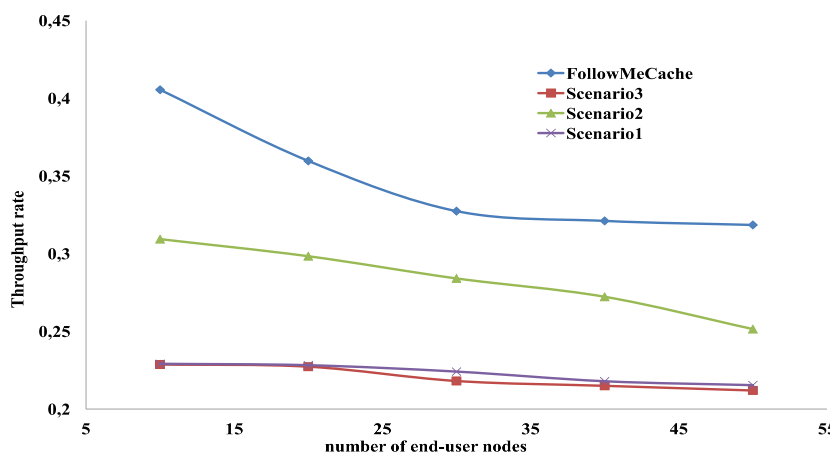

Fig. 8. Throughput rate vs number of nodes.

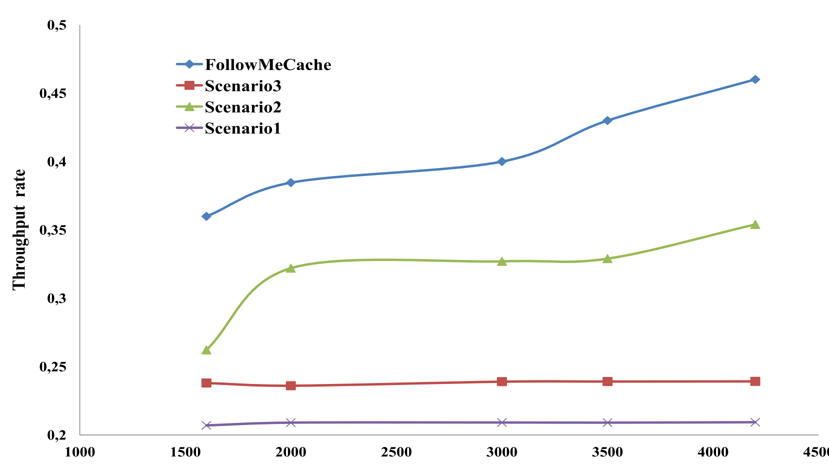

Fig. 9. Throughput rate vs coverage area of ZI.

area. This is why it is constant. On the other hand, FollowMeCache and Cache on the Move algorithms take into consideration the ZI areas: When the area is large, it includes more nodes and the cache nodes and the offloaded content can be decreased.

Finally, Fig. 13 shows Overhead ratio over various user density. We see that overhead ratio of greedy scheme is substantially higher. Overhead ratio of our scheme and Cache on the Move method decreases over increase in number of nodes and FollowMeCache approach outperforms Cache on the Move approach. Thanks to ICN/NDN approach, less cache nodes can satisfy more clients while with greedy algorithm data must go through many hops to reach destination. This result is better depicted in Fig. 14

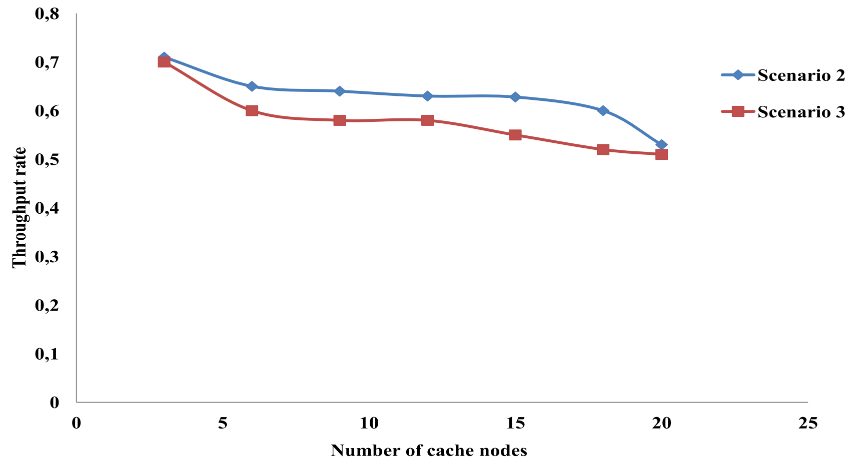

Fig. 10. Throughput rate vs number of cache nodes.

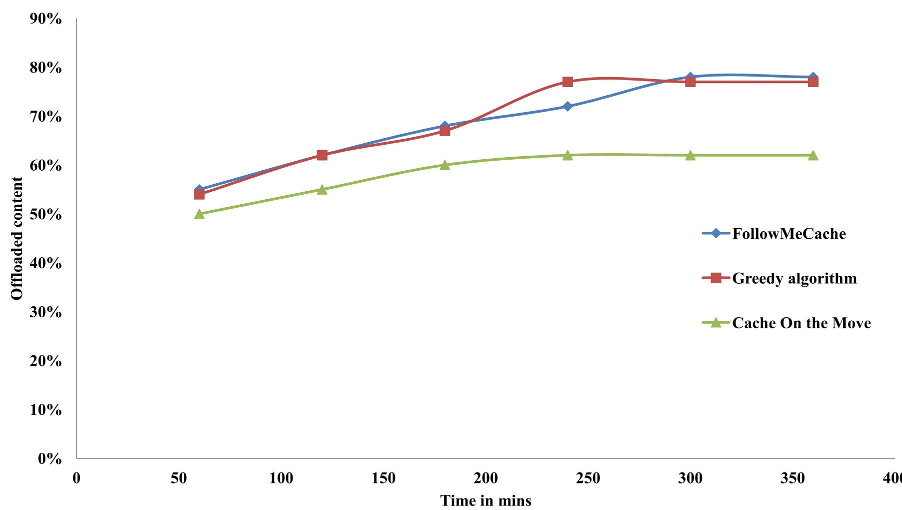

Fig. 11. Offloaded content vs time.

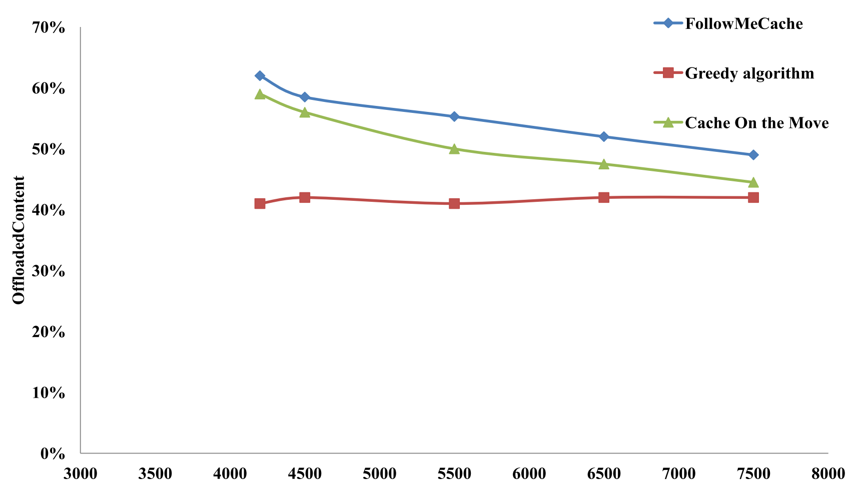

Fig. 12. Offloaded content vs ZI coverage area.

where we calculate for each approach the end to end delay. This graph shows that by increasing the number of nodes in the network, we need more time to get the required video. In other hand, we can observe that end to end delay of greedy scheme is higher than FollowMeCache and cache On the Move approaches where the content is more closer to the end user thanks to the

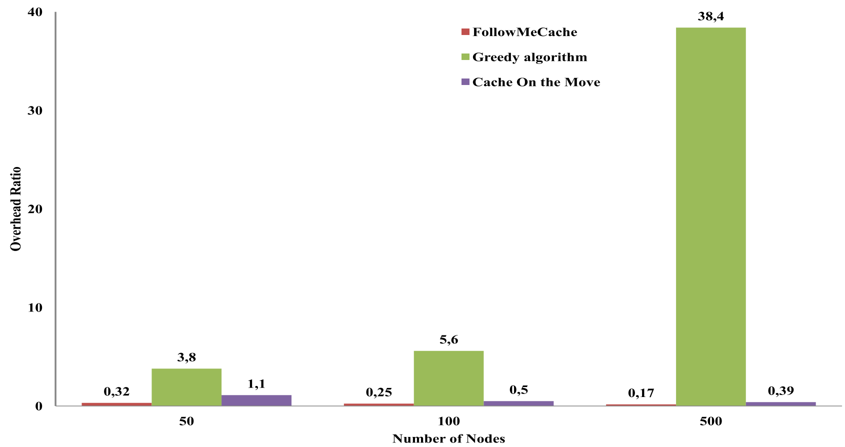

Fig. 13. Overhead Ratio vs number of nodes.

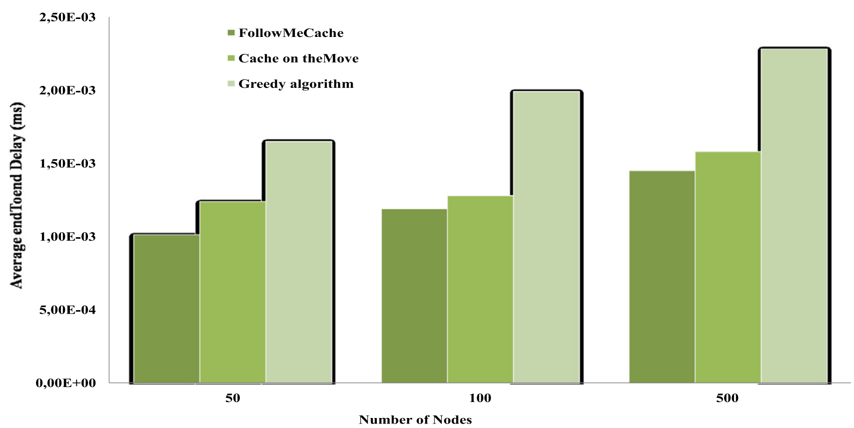

Fig. 14. End to End delay vs number of nodes.

optimal selection of cache nodes. Besides, the main drawback of greedy solution is that very often, it does not provide a globally optimum solution when making the locally optimal choice.

6. Conclusion

In this paper, we proposed a new hybrid and programmable architecture based on SDN/ICN and CDS approach. The main aim of our proposed architecture is to reduce the use of cellular communication link by selecting specific nodes named cache nodes. In order to select these nodes, we proposed a new algorithm called Cache node selection CNS. Unlike the existing cache node selection methods that use only the connectivity degree and node capacity, our method focuses on the geographic position of nodes around the ZI, the preference of end-user and the LQI between 2 nodes.

In order to evaluate the performance of the proposed algorithm, we compared it to other scenarios and existing caching solutions. The obtained simulation results in different simulation cases point that the proposed algorithm outperforms other methods and give significant gain in terms of QoE, network throughput and the transmission delay, Overhead ratio and offloaded content.

CRediT authorship contribution statement

Tasnim Abar: Conceptualization, Methodology, Software, Investigation, Writing - original draft, Writing - review & editing. **Abderrezak Rachedi:** Conceptualization, Methodology, Writing - review & editing, Visualization, Supervision, Validation. **Asma ben Letaifa:** Visualization, Supervision, Validation, Writing - original draft. **Philippe Fabian:** Methodology, Software, Investigation. **Sadok el Asmi:** Supervision, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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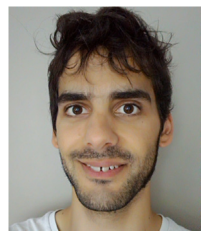

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