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Research Article

A Novel Link-Network Assignment to Improve the Performance of Mobility Management Protocols in Future Mobile Networks

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5G is expected to support new services and applications that will change the user experience and will drive to a new business landscape. Moreover, most of the services will require optimum connectivity and seamless mobility in heterogeneous networks. To cope with these challenges, network mobility management and network densification are envisioned to be key factors in the emerging 5G architectures. By deploying a large number of cells, 5G architectures can provide users with high throughput and flexible access services, an improvement of the network scalability and optimized network coverage. However, with this densification, seamless mobility support can lead to significant increasing in signaling overhead due to frequent handovers. In this context, network operators need to efficiently plan the deployment of the base stations taking into account the mobility management of the users, and the service degradation that this mobility process could cause. This article aims to optimize the assignment of the base stations to the access routers in the mobile network to improve the network performance. The results obtained show that our proposed Link-Network Assignment algorithm based on clustering techniques achieve significant gains in terms of signaling and data forwarding costs. These simulation results demonstrate that the proposed algorithm can successfully reduce signaling cost and packet delivery cost by up to 56% and 5%, respectively, on average, compared with baseline algorithms.

1. Introduction

5G is the evolution of mobile networks which provides higher rates in the transmission, analyzes and manipulates massive amounts of data and applications quickly, and manages the network resources efficiently than ever before.

In this sense, 4G was developed to provide mobile broadband communications to the users; whereas, 5G is conceived as a key technology because it combines entities, communications, and control technologies [1]. 5G is appropriated to support enhanced mobile broadband communications, ultra-reliable low-latency communications (URLLC), and massive machine-type communications (mMTC) [2, 3].

The 3GPP architecture implemented in 4G manages the mobility from a centralized scheme [4]. These Centralized Mobility Management (CMM) protocols [5] introduce a mobility anchor that is responsible for data forwarding and signaling traffic management. In the 4G architecture, these nodes are the packet gateway (PGW), which acts as mobility anchor; the serving gateway (SGW); and the

evolved Packet Data Gateway (ePDG) which implements the signaling agent functions and eNode B (eNB) which provides the radio access network. However, some issues affect centralized mobility management protocols, such as nonoptimal routing, scalability problems, and centralized anchors [4, 6].

The architecture in 5G defines a set of functions to handle mobility. These network functions (NF) are defined using a service-based architecture and allow to manage the mobility deploying a distributed scheme [7]. Distributed Mobility Management (DMM) protocols [8, 9] propose to locate closer to the user the mobility anchors to achieve a flatter network. In the 5G architecture, the entities involved in the nodes' mobility are the Access Mobility Manager (AMF) and the Session Management Function (SMF) which assist and manage the control plane of the communication. The User Plane Functions (UPF) is also involved in the 5G architecture, being the data forwarding entity. Then, UPF and SMF replace the entities SGW and PGW deployed in 4G. In this architecture, UPFs are closer to the users acting as mobility anchor towards the access network [10]. In particular, the 5G access network can be a radio access network or any non-3GPP access network, such as WLAN.

The UPF has a key role in the deployment of the Multi-access Edge Computing (MEC) in a 5G network, some specific implementations can include this element as part of the MEC [11]. The MEC approach is implemented in a cloud datacenter located at the edge of the mobile network and distributes computation and storage capabilities reducing communications distance and, consequently, the delay between the mobile network and end-users. This approach also improves the maintenance of the user connectivity, implementing new network functions that provide L3 (network level) mobility support by maintaining active communications when the mobile user performs its movement through the mobility domain.

This new 5G architecture comprising of new radio and core network looks to fulfil the requirements on higher bandwidth and reliability, lower latency, an increment of the network efficiency, and a much higher network densification. To achieve this, operators must plan the resources efficiently to improve the network performance. In this sense, the signaling overhead introduced to manage the user mobility between different access networks and also to handle the IP mobility management increase the latency of the communication.

The main contributions of this paper are summarized as follows:

(a) The optimization problem is formulated to minimize the impact of base stations assignment to access routers in terms of signaling and data forwarding costs associated with the mobility management protocols

(b) A novel Link-Network Assignment algorithm is proposed for planning future mobile networks. This algorithm collects information from the access network topology and examines the base stations distribution in order to perform an appropriate assignment

(c) A performance evaluation is conducted to show the benefits of the proposed algorithm in terms of well-known mobility costs

This work proposes a mechanism to plan the most appropriate association between base stations and the access nodes to reduce the signaling of the network and improve the performance of mobility protocols in 4G and 5G.

The rest of this paper is organized as follows. Section II describes the background of the work, presenting the most representative mobility management solutions and the analyzed problem. In Section III, the proposed system model and the Link-Network Assignment problem are formulated. In Section IV, the metrics to evaluate the performance of the mobility management protocols are discussed. The considered simulation setup and experimental results are presented and discussed in Section V. Lastly, the conclusions and future works are summarized in Section VI.

2. Background

The densification of the network is introduced to address the huge service demands in 5G. The next-generation radio access network (RAN) will be a mixture of various types of RANs macrocells base stations (BSs), femtocell BSs, picocell BSs, and WiFi Access Points. The infrastructure that interconnects those radio access networks with the Internet must provide ubiquitous device connectivity providing seamless mobility support at the network layer.

As seen before, many protocols deploy IP mobility management in the network to provide seamless mobility support. This section presents an overview of the two most representative approaches to mobility management, Proxy Mobile IPv6 (PMIPv6) and Distributed Mobility Management (DMM).

2.1. Centralized Mobility Management. PMIPv6 is the most characteristic centralized mobility management protocol [12]. In this approach, a single mobility anchor manages the signaling and traffic of the Mobile Nodes (MNs). PMIPv6 manages mobility by introducing the Mobile Access Gateway (MAG) and the Local Mobility Anchor (LMA), which usually are deployed in the SGW and PGW, respectively, in the 4G architecture. The main role of the MAG is to manage the mobility signaling for an MN that is attached to it, establishing a tunnel with the LMA. The LMA ensures the MN address remains reachable when it performs the movement across the mobility domain. The generic architecture of PMIPv6 is shown in Figure 1.

When an MN connects to a network domain, its traffic is anchored to the LMA and is encapsulated in a tunnel between the LMA and MAG. When the MN performs a handover from MAG-1 to MAG-2, as shown in Figure 1, the binding is updated at the LMA using Proxy Binding Update (PBU) and Proxy Binding Acknowledgement (PBA) messages. Then, a new tunnel is established between

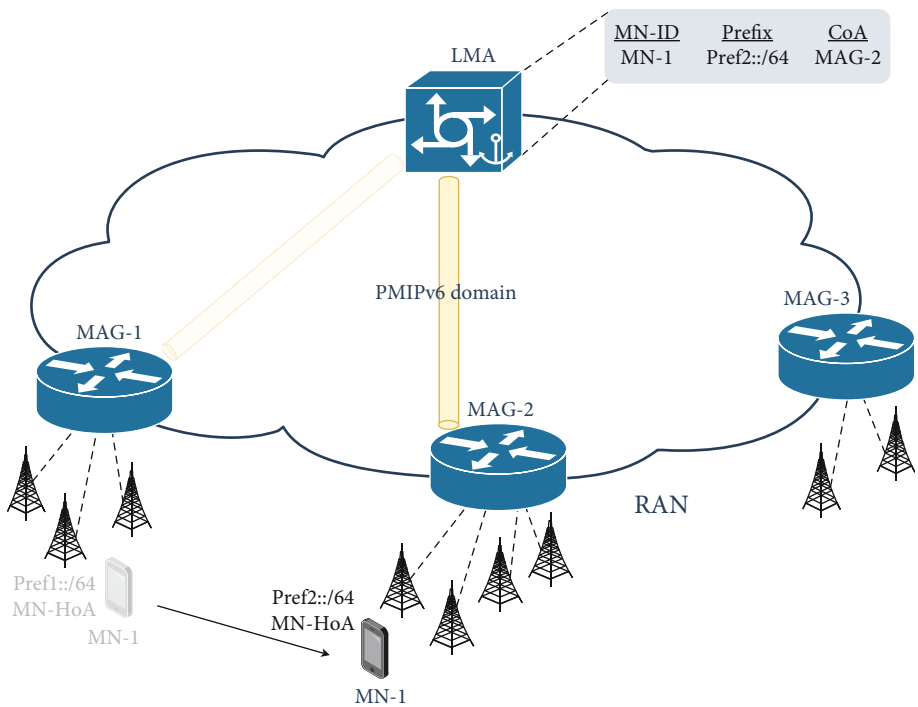

Figure 1: Centralized Mobility Management solution: Proxy Mobile IPv6.

MAG-2 and the LMA to keep the ongoing IP traffic flows active.

2.2. Distributed Mobility Management. Centralized approaches have several problems and limitations that have been identified in [8, 9]: nonoptimal routing, signaling overhead, and scalability and reliability issues. These limitations have recently propelled the emergence of Distributed Mobility Management. In this approach, the mobility anchors are located and distributed closer to the user, reducing the traffic bottlenecks that affect mobile networks at this time.

A representative proposal of a DMM is Network-Based DMM (NB-DMM) [8]. NB-DMM is a network-based DMM approach, as PMIPv6. This means that the MN does not need to participate in the process of signaling issues related to mobility. Therefore, it is not necessary to update the mobile node's protocol stack. In this protocol, the mobility management functionalities are moved to the Access Routers (ARs) or an entity with similar features in 5G to anchor the traffic closer to the MN. These entities, called mobility capable access router (MAR), distribute the control and data plane mobility functions along the edge of the access network. The generic architecture of NB-DMM is depicted in Figure 2.

In NB-DMM, when an MN connects to a network domain, its traffic is anchored at the serving MAR.

However, when the MN performs a handover from MAR-2 to MAR-3, as shown in Figure 2, the data traffic of the session is tunneled between the serving MAR (MAR-3) and the anchoring MAR (MAR-2). Thus, upon a handover, the new MAR needs the IP addresses of each previous MAR with active MN's sessions. These addresses are obtained from the mobility database. Then, the new MAR notify to each previous MAR, by sending a PBU message, in order to update the location of the MN. Each anchoring MAR replies by a PBA.

2.3. Link-Network Assignment Problem. Recently, the academia and the industry have analyzed the different assignment problems in 5G where the principal one is the user assignment to a Base Station in heterogeneous networks [13]. These solutions focus on determining the users (devices) belonging to each base station, addressing the issues of user association in the network, and studying parameters related to physical and data link layers [14]. However, neither solution discusses the association between the stations and the mobile access network, analyzing and improving the behavior of IP mobility management protocols.

Many works often improve some objective in the wireless network like energy [15]. In this work, power consumption is analyzed in a multi-connectivity environment, in which devices are associated with multiple radio access technologies, simultaneously. In [16], the goal is to achieve load balancing in the association between users and base stations taking advantage of the effectiveness in offloading users provided by 5G. Other authors focus on optimizing user association to achieve proportional fairness function among different users of the network [17]. All these solutions also do not consider the association between base stations and the access network, nor the improvement of IP mobility management in 5G environments.

Otherwise, unlike our proposal, works directly related to mobility management protocols [4–9] do not provide performance improvements through the association between the access network and base stations. The solutions based

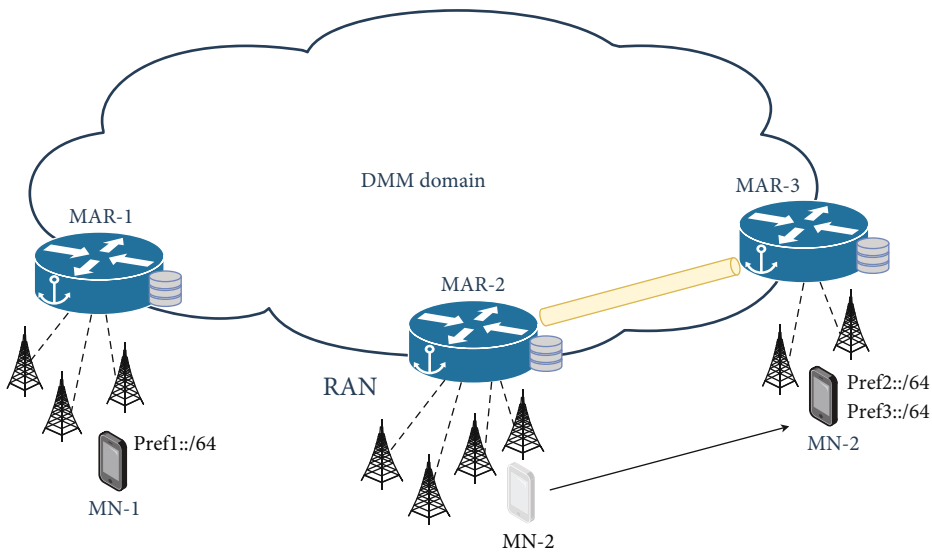

Figure 2: Network architecture of the Distributed Mobility Management solution.

on mobility management in 5G-enabled networks generally focus on protocols [18].

Other works study the ability provided by network slicing to assign different sliced radio access networks to various core slices [19–21]. However, these proposals concern requirements for allocating a 5G network slice, without taking into consideration the mobility management protocols.

In this paper, a Link-Network Assignment problem is proposed to improve the performance of mobility management protocols in 5G. To the best of our knowledge, this assignment problem and its solution for future mobile networks analyzing mobility management protocols have not yet been proposed before. All analyzed solutions have taken into account base stations and users to improve the communication. In this approach, the optimization minimizes the signaling of the mobility management protocol, and the latency introduced when a handover is produced. Both of them can be a key aspect to improve in ultrareliable and low-latency communications proposed by the 5G standard. In general, mobility management solutions aim to balance the signaling overhead generated during the movement process with the packet delivery cost caused by the suboptimal routing imposed by the protocols when the user is roaming among different networks. In these cases, the decrease in one of the costs impacts negatively on the other and vice versa. It is worth noting that our solution does not require the modification of any mobility management protocol involved in the communication.

3. System Model and Problem Formulation

In this section, the system model is introduced in order to define the optimization problem to minimize the impact of base stations assignment to access nodes, without loss of performance in terms of packet delivery (P_{cost}) and signalling (C_u) costs associated with mobility management protocols.

3.1. Mobility Domain and Access Network. Let a given access network be represented as an undirected graph $G = (V, E)$, where V and E denote the sets of nodes and links (edges), respectively. Let $K \subseteq V$ be the set of access routers that give access to mobile users through a set of base stations B, where each base station is denoted by $b_i (1 \leq i \leq |B|)$. This set B provides full coverage to a geographical area under consideration and each location is given by $\{L_{b_i}\}_{b_i \in B}$, where $L_{b_i} \in \mathbb{R}^2$ represents the bidimensional space where base stations will be located.

3.2. Base Station Assignment and Mobile Nodes Support. Each access router $\{k_j\}_{j \in K}$ serves a given number of base stations $B_k \subseteq B$ within a network domain. The access routers are defined as the first-hop routers, which can be taken as the link between physical and network levels. Furthermore, N denotes the set of mobile nodes which moves around the network where each mobile node is defined by $N_j (1 \leq j \leq |N|)$, and it is attached to base station $b_i \in B$.

Moreover, let us assume that each base station b_i is linked to a mobility domain access router, as shown in Figure 3, and each access router k_j manages a set of base stations.

3.3. Link-Network Assignment Problem. The optimal assignment between the access network and base stations set is defined as the following optimization problem:

$$\underset{x_{mr}^{ps}}{\text{Min}}\ F = \sum_{m \in B} \sum_{r \in K} \sum_{p \in B} \sum_{s \in K} T C x_{mr}^{ps}, \tag{1}$$

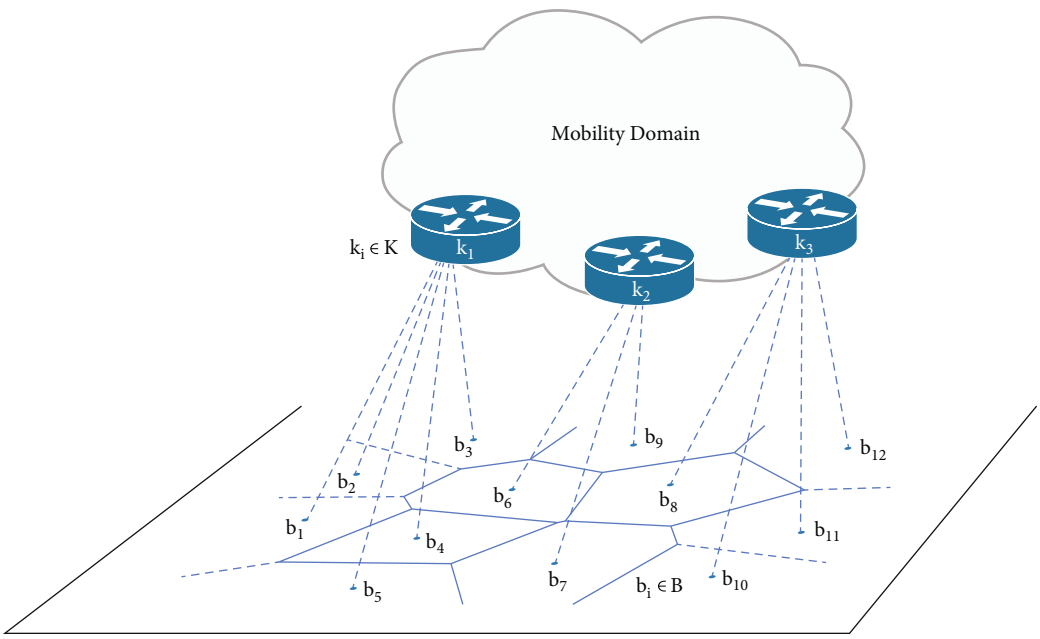

Figure 3: Base stations assignment to mobility domain.

subject to:

$$\begin{gathered}\sum_{r\in K}\sum_{p\in B}\sum_{s\in K} x_{mr}^{ps} + \sum_{m'\in B}\sum_{r'\in K}\sum_{s'\in K} x_{m'r'}^{p's'} = 1,\\ \forall m = p' \in B, m = p' = 1, \cdots, B\\ \sum_{m\in B}\sum_{p\in B}\sum_{s\in K} x_{mr}^{ps} + \sum_{m'\in B}\sum_{r'\in K}\sum_{p'\in B} x_{m'r'}^{p's'} \le th_j,\\ \forall r = s' = j \in K, r = s' = j = 1, \cdots, K\\ x_{mr}^{ps} \in \{0, 1\}, \forall m \in B, r \in K, p \in B, s \in K.\end{gathered} \tag{2}$$

Being x_{mr}^{ps} a binary decision variable defined as:

$$x_{mr}^{ps} = \begin{cases} 1 & \text{if base station } m \text{ isassigned to the access} \\ & \text{router } r \text{ and base station } p \text{ is assigned to} \\ & \text{the access router } s. \\ 0 & \text{otherwise.} \end{cases} \tag{3}$$

For each assignment, the total cost TC is defined as the sum of the main parameters related to mobility management protocols, signalling cost, and packet delivery cost:

$$TC = C_u(\cdot) + P_{cost}(\cdot) \tag{4}$$

Signaling cost considers the traffic load in bytes generated by signaling messages when a layer three handover process occurs in order to maintain the active sessions of each mobile node (MN). Packet delivery cost, calculated in bytes, measures the cost to forward the data packet in the network. It depends on the size of the data messages and the number of hops needed to forward packets to the MN. Both measurements will be explained in deep in Section 4. Constraint 2 indicates that a base station ($m = p' \in B$) is assigned to a single access router, and constraint 3 is related to the balance of base stations between the different access routers. The assumption is that a given access router ($r = s' \in K$) cannot serve more than a specific number of base stations, determined by a threshold (th_j).

3.4. Link-Network Assignment Algorithm. The above model computes of the optimal assignment between the physical level and the access network. In this context, the problem size depends on the number of base stations and the nodes of the access network. When the problem size is reduced, for instance, 15 base stations and 3 routers, an optimal solution is found in less than a second. Nevertheless, if the number of base stations increases and large-scale topologies of the access network are used, the time complexity increases exponentially. The optimal bind between base stations and the access network has become a challenge that has to be addressed for future mobile network operators. For this reason, a new strategy is proposed to solve this problem at a weak polynomial time. Thus, Algorithm 1 defines the link-network assignment algorithm exhaustively.

The proposed algorithm collects the information from the access network topology and examines the base stations distribution in order to perform an appropriate assignment. It is composed of three steps that are defined as follows:

(a) *First step*. A set of data observations (base stations set $B = \{b_1, \cdots, b_{|B|}\}$) are classified into a specific

Input: Base stations set $B = \{b_1, \cdots, b_{|B|}\}$, access routers set $K = \{k_1, \cdots, k_{|K|}\}$ and network topology NT
Output: Dictionary *DictAssoc* with final relation between base stations clusters (centers) and access routers
▷**first step**
C = k-means++$(B, |K|)$;
▷**second step**
D_{CKM} = getEuclideanDistances(C) ;
D_{AR} = allShortestPath(NT, K) ;
▷**third step**
For $c_i \in C$ **do**
  $M_C[i] = \sqrt{c_{ix}^2 + c_{iy}^2}$
End for
For $k_i \in K$ **do**
  $CC_{AR}[j] = |K| / \sum_{k_j \in K} D_{AR}[k_i][k_j]$
End for
▷**fourth step**
$MC = argmax(M_C)$; $cc = argmin(CC_{AR})$
For $j = 1$ to $|K|$ **do**
  $d_c[j] = D_{CKM}[MC][j]$;
  $d_{ar}[j] = D_{AR}[cc][j]$;
End for
d_c = sorted(d_c) ; d_{ar} = sorted(d_{ar})
For $i = 1$ to $|K|$ **do**
  $DictAssoc\{\text{“}d_c[i]\text{”}\} = d_{ar}[i]$;
End for
Return *DictAssoc* ;

Algorithm 1: Link-network assignment algorithm.

number of $|K|$ clusters, matching the number of access routers using a widely known unsupervised algorithm called k-means++ algorithm [22]. This algorithm presents an evolution for centroids initialization in order to improve the computational time that can become exponential if the original algorithm is used. Thus k-means++ minimizes the distance between observations and centroids using Euclidean distance, and it includes an initialization method based on a uniform random variable. This method allows a proper set of initial cluster centroids to be obtained

(b) *Second step*. For each centroid c_i, the distances $D_{CKM}(i, j)$ between c_i and all others ($c_j \in C$) are calculated using Euclidean distance. Then, the distance matrix of topology access nodes D_{AR} is built: for each topology access router k_i, the distance with the others ($k_j \in K$) is computed through Dijkstra algorithm

(c) *Third step*. Our algorithm selects the highest centroid modulus value. Each centroid c_i in a bidimensional space is defined as $c_i = [c_{ix}, c_{iy}]$. Thus, the Euclidean norm or modulus of each centroid can be calculated as the square root of the sum of the squared centroid values

  (a) Moreover, for each access router $k_i \in K$, closeness centrality [23] is computed according to Equation (5) in order to select the node with minimum value.

  (b)

$$CC_{AR}(k_i) = \frac{|K|}{\sum_{k_j \in K} D_{AR}(k_i, k_j)} \tag{5}$$

(d) *Fourth step*. Then, the algorithm performs the first association between the highest centroid modulus value MC and the access router with minimum value of closeness centrality cc. Once this is done, vectors distance d_c and d_{ar} are extracted; d_c indicates the distance between MC and all others; and d_{ar} stores the distance between cc and all others. Finally, both vectors are sorted in ascending order and the final association is performed

Figure 4 shows an example of the proposed method in operation. In this case, the access network topology consists of three routers. Therefore, the base stations set is clustered into three groups through the k-means++ algorithm. Then, the proposed Algorithm 1 performs the final assignment, as described above.

4. Performance Metrics

The performance metrics, described in this section, evaluate both NB-DMM and PMIPv6 approaches by means of

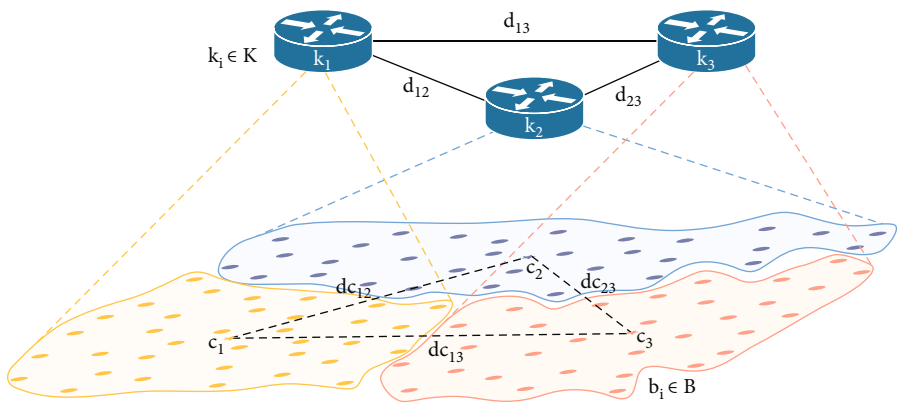

Figure 4: Example of proposed link-network assignment algorithm for three access routers.

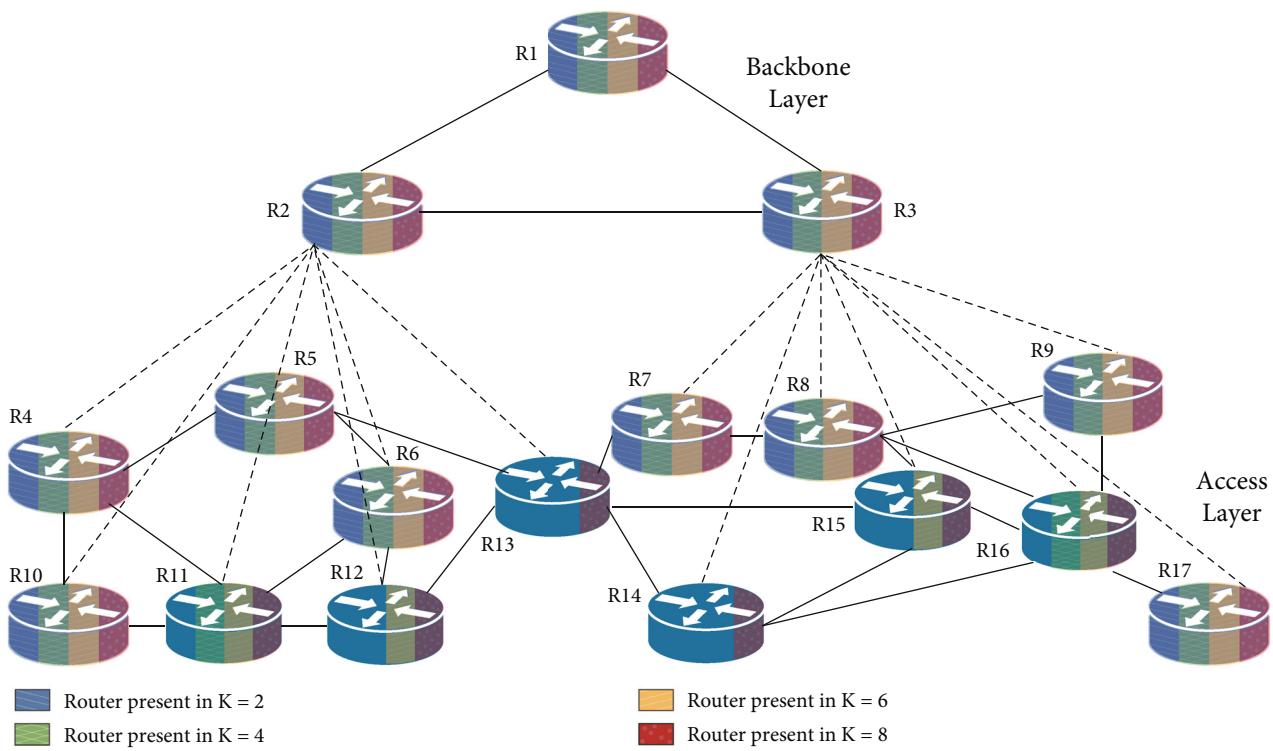

Figure 5: The city network topology used in the simulations.

Table 1: Functions of the nodes of the network topology for $K = 8$.

	R1	R2–R9	R10–R17
PMIPv6 approach	LMA	Router	MAG
NB-DMM approach	Router	Router	MAR

assessing the signaling cost, the packet delivery cost, and the signaling delay.

The packet transmission cost in IP networks is proportional to the number of hops between source and destination nodes. Thus, the transmission cost of a packet (signaling or data) between nodes X and Y can be expressed as $C(\cdot) = Size_{\text{Packet}} d_{X-Y}$.

4.1. Control Plane. The mobility support comprises the process of maintaining the MN's sessions while users move through the mobility domain. For this purpose, mobility management protocols are responsible for this process and use signaling messages between the mobility agents.

In order to evaluate the control plane, an important metric is the accumulative traffic overhead in bytes on exchanging signaling messages during the communication session of the MN. Thus, the total cost of signaling for a mobility session is expressed as $C_u(\cdot)$, where $(\cdot)$ is one of the analyzed approaches (PMIPv6 or NB-DMM). This cost is directly proportional to the size of the control messages and the distance in number of hops in each handover during the time interval that the MN communication remains active. In

Table 2: Simulation parameters.

Parameter	Value
Total number of routers	17
Number of access routers (K)	2,4,6,8
Simulation scenario	10×10 km^2
Velocity of mobile users	1–20 m/s
Number of mobile users	200
Average rate of Poisson process (λ)	0.01
Duration of a session (μ)	10
Flow rate of a request	1.5–10 Mbps
Confidence interval	95%
Number of iterations	500

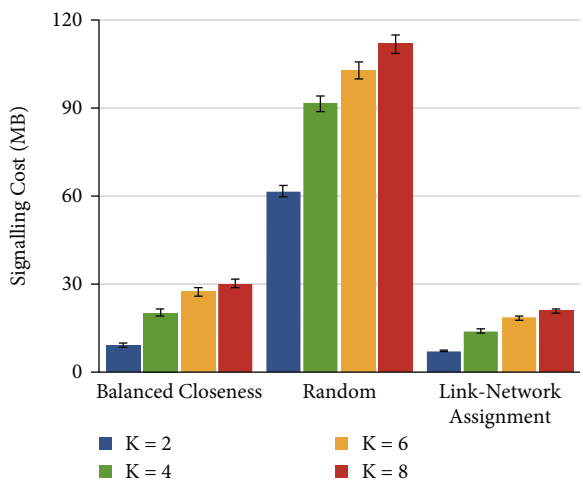

Figure 6: Control plane evaluation of centralized mobility protocol using different assignment algorithms.

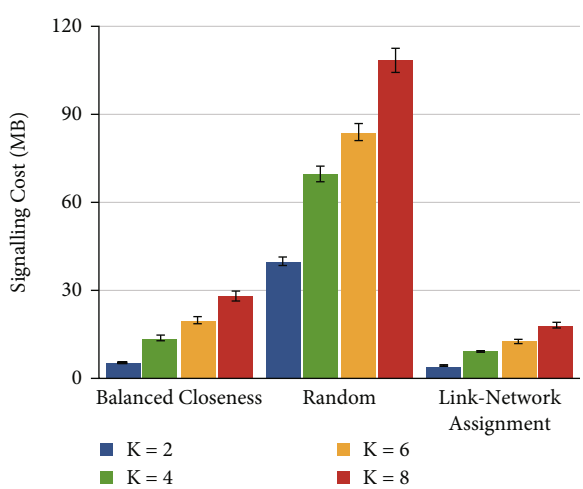

Figure 7: Control plane evaluation of distributed mobility protocol using different assignment algorithms.

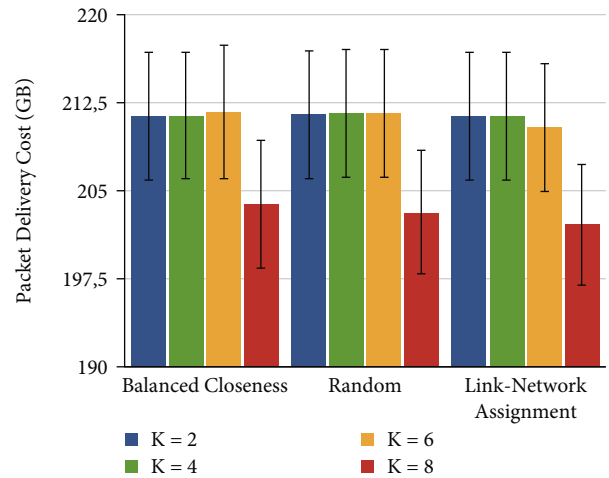

Figure 8: Data plane evaluation of centralized mobility protocol using different assignment algorithms.

PMIPv6 ($C_u(PMIP)$), the registration update is needed with the mobility anchor (LMA). On the other hand, in DMM ($C_u(NB-DMM)$), the serving MAG ($SMAR$) retrieves information of the previous MAR's ($PMAR_i$) with an active session, and it establishes IP-IP tunnels with them.

Hence, the following expressions represent the signaling cost for both solutions:

$$\begin{aligned} C_u(PMIP) &= 2s_u h_{MAG-LMA}. \\ C_u(NB-DMM) &= 2s_u + 2s_u \sum_{i=1}^{nActiveMAR-1} \left(h_{PMAR_i-SMAR}\right). \end{aligned} \tag{6}$$

Where s_u is the size of the PBU message and $nActiveMAR$ is the number of MAR with an active session anchored for a particular MN.

4.2. Data Plane. Regarding the data plane, one of the metrics that have a major impact on the overall performance of the network is the packet delivery cost ($P_{cost}(\cdot)$). Apart from the signaling related to the mobility management process, data packets have to be forwarded from the CN (Correspondent Node) to the MN and vice versa. In CMM solutions, the data is first routed to the centralized anchor, causing a suboptimal routing and a single point of failure in the network. In order to address these problems, new DMM solutions have been designed. Therefore, the packet delivery cost for a session is proportional to the size of the data messages and the number of hops needed to forward packets to the MN.

In PMIPv6, the packets are routed to the mobile user via the LMA through a tunnel that encapsulates the data packets. In NB-DMM protocols, when the handover process occurs, the traffic in the new location will be routed directly to the peer (direct mode), whereas the remaining connections will be tunneled to the user's corresponding anchoring

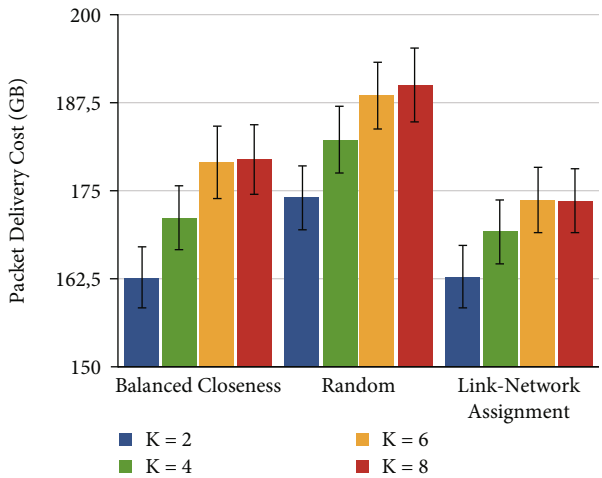

Figure 9: Data plane evaluation of distributed mobility protocol using different assignment algorithms.

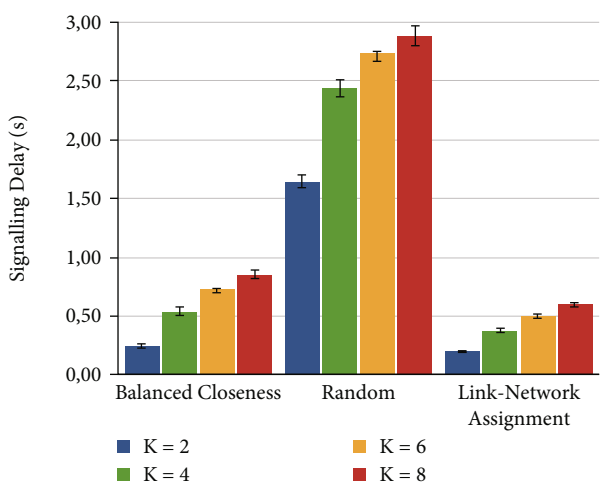

Figure 10: Average signaling delay evaluation of centralized mobility management protocol using different assignment algorithms.

MAR, and then routed to the destination peer (indirect mode).

Thus, the expressions that represent the cost are as follows:

$$P_{cost}(PMIP) = [s_d h_{CN-LMA} + (s_t + s_d)h_{LMA-MAG} + s_d h_{MAG-MN}]N_{p/s}.$$

$$P_{cost}(NB-DMM) = [P_n P_{cost}(direct) + P_h P_{cost}(indirect)]N_{p/s}. \tag{7}$$

Where $N_{p/s}$ is the packet transmission rate per active flow, s_d is the size of these data messages and s_t is the average size of the tunnel header. Moreover, P_n and P_h are, respectively, the probabilities that the traffic is new or it is handover traffic. $P_{cost}(direct)$ and $P_{cost}(indirect)$ are the units of cost of delivering one packet in the direct and indirect

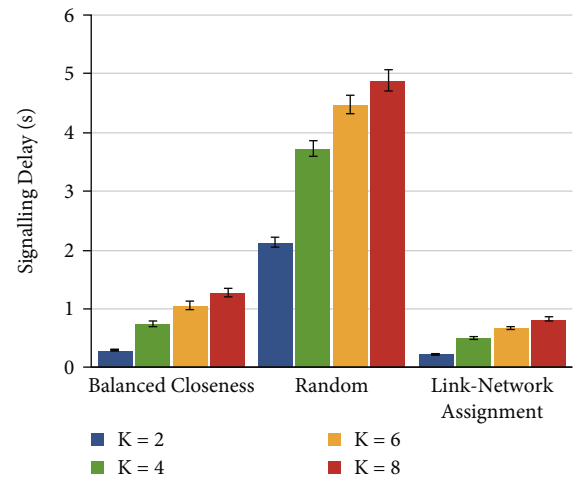

Figure 11: Average signaling delay of distributed mobility management protocol using different assignment algorithms.

modes of DMM, respectively. Then these costs are expressed as follows:

$$P_{cost}(direct) = s_d h_{CN-SMAR} + s_d h_{SMAR-MN}.$$

$$P_{cost}(indirect) = (s_t + s_d)h_{PMAR-SMAR} + s_d h_{SMAR-MN} + s_d h_{CN-PMAR}. \tag{8}$$

4.3. Signaling Delay. As seen before, the L3 handover requires a control message between different entities to maintain the established communications while the MN is moving across the network. These control messages introduce a delay in the communication that deteriorates the low-latency communications promoted in 5G. Assuming that packets are transmitted in a first-come-first-served manner, the signaling packets in the network can be transmitted only after all the packets before it has been transmitted. In this analysis, the propagation latency of the transmission medium is not considered.

Consequently, the signaling delay $\delta(\cdot)$ for both solutions is summarized in the following expressions:

$$\begin{aligned} \delta(PMIP) &= \frac{2s_u + (2s_u h_{MAG-LMA})}{B_w}, \\ \delta(NB-DMM) &= \frac{2s_u + (2s_u nActiveMAR)}{B_w}, \end{aligned} \tag{9}$$

being B_w is the mean bandwidth of the links.

5. Results

This section aims at providing insights into the impact of several mobility costs on the overall network performance and evaluating the proposed algorithm using different topologies. These topologies are based on city network topologies [24] by varying the number of access routers ($K = \{2, 4, 6, 8\}$). Figure 5 shows the network topology with eight access

Table 3: Evaluation of mobility protocols using different assignment algorithms between base stations and access routers.

Centralized mobility protocol-PMIPv6					
Algorithm analysis		$\|K\| = 2$	$\|K\| = 4$	$\|K\| = 6$	$\|K\| = 8$
	$C_u(MB)$	9.35 ± 0.59	20.35 ± 1.24	27.43 ± 1.36	30.23 ± 1.42
Balanced closeness	$P_{cost}(MB)$	211380.49 ± 5401.64	211409.27 ± 5403.60	211722.41 ± 5632.99	203830.82 ± 5437.97
	$T_D(s)$	12.47 ± 0.78	27.14 ± 1.65	36.55 ± 1.78	42.78 ± 1.78
	$C_u(MB)$	61.76 ± 2.06	91.57 ± 2.62	102.92 ± 2.91	111.93 ± 3.06
Random	$P_{cost}(MB)$	211518.15 ± 5405.48	211596.41 ± 5413.47	211638.96 ± 5413.47	203178.27 ± 5235.02
	$T_D(s)$	82.35 ± 2.75	122.10 ± 3.401	137.17 ± 3.9	144.35 ± 3.98
	$C_u(MB)$	7.46 ± 0.40	14.21 ± 0.52	18.74 ± 0.65	21.03 ± 0.70
Link-network assignment	$P_{cost}(MB)$	211375.93 ± 5401.83	211393.59 ± 5402.16	210442.95 ± 5432.32	202162.96 ± 5123.51
	$T_D(s)$	9.95 ± 0.53	18.95 ± 0.70	25.11 ± 0.84	29.87 ± 1.00
Distributed mobility protocol-NB-DMM					
Algorithm analysis		$\|K\| = 2$	$\|K\| = 4$	$\|K\| = 6$	$\|K\| = 8$
	$C_u(MB)$	5.60 ± 0.39	13.84 ± 0.94	19.88 ± 1.18	28.27 ± 1.59
Balanced closeness	$P_{cost}(MB)$	162737.46 ± 4284.03	171150.97 ± 4523.40	179118.25 ± 5096.63	179529.07 ± 4982.56
	$T_D(s)$	14.92 ± 1.03	36.91 ± 2.50	53.01 ± 3.14	63.53 ± 3.45
	$C_u(MB)$	39.97 ± 1.49	69.88 ± 2.58	83.96 ± 2.99	108.53 ± 4.14
Random	$P_{cost}(MB)$	174055.86 ± 4540.51	182291.82 ± 4728.63	188613.12 ± 4729.96	189995.44 ± 5231.66
	$T_D(s)$	106.60 ± 3.97	186.35 ± 6.88	223.89 ± 7.98	244.27 ± 9.15
	$C_u(MB)$	4.36 ± 0.26	9.41 ± 0.43	12.79 ± 0.56	18.29 ± 0.80
Link-network assignment	$P_{cost}(MB)$	162933.91 ± 4390.05	169223.20 ± 4490.39	173769.60 ± 4661.60	173569.57 ± 4547.01
	$T_D(s)$	11.62 ± 0.69	25.08 ± 1.15	34.09 ± 1.43	41.31 ± 1.76

routers (R10–R17). The other topologies ($K = \{2, 4, 6\}$) used in our simulations are based on this. For example, for $K = 2$, R11–R16 network nodes are removed from the access layer. Accordingly, for $K = 4$, the topology consists of R1-R11 and R16-R17 nodes. Finally, for $K = 6$, R13–R14 nodes are removed from the topology. Note that, each network node plays a determining role listed in Table 1.

Several topologies have been selected in order to provide more reliable results, avoiding the misleading performance of centralized or distributed protocols. The traffic and mobility parameters used in the simulations, as well as the numerical results of mobility costs, are presented next.

We run a MonteCarlo simulation of 500 iterations providing the average values and improving the accuracy of the results with a confidence interval of 95%. The proposed association algorithm is tested through simulations using Python with NetworkX and SciPy libraries [25], among others.

The simulation scenario is a square region of 10×10 km^2 of area, where the base stations are distributed according to a Poisson Point Process (PPP) whose intensity (λ_{BS}) coincides with the average number of BS (N_{BS}) per unit area (A) [26] and is obtained as $\lambda_{BS} = N_{BS}/A$. Moreover, the BS coverage areas are modeled as Poisson-Voronoi tessellation on the bidimensional plane where each mobile user is connected to the closest BS.

User mobility is defined by a Random Waypoint with a uniformly distributed velocity between 1 and 20 m/s. Each simulation consists of 200 mobile users who move across the mobility domain by connecting to different Base Stations. These mobile users manage a set of sessions during the simulation time. It is assumed that each mobile user receives incoming sessions following a Poisson process with an average rate of $\lambda = 0.01$. Moreover, the duration of a session is exponentially distributed with parameter $\mu = 10$ [27]. It is also assumed that the flow rate requirement of a request varies from 1500 Kbps to 10 Mbps (e.g. video streams) [28]. The parameters that have been used in the simulations are presented in Table 2.

The performance of the proposed algorithm is evaluated over this network scenario by calculating the performance metrics analyzed before signaling ($C_u(\cdot)$) and packet delivery cost ($P_{cost}(\cdot)$). Moreover, to investigate how the link-network assignment affects the performance of the mobility management protocols, a set of simulations have been conducted over the aforementioned centralized and distributed mobility management protocols (PMIPv6 and NB-DMM, respectively) using different network topologies ($K = \{2, 4, 6, 8\}$).

Figures 6 and 7 show the accumulated signaling cost for all connections generated during the simulation to provide a comparison of this metric as a function of the number of access routers for CMM and DMM protocols, respectively.

In these evaluations, the performance of the Link-Network Assignment algorithm proposed obtains better results compared with the other approaches analyzed, The random algorithm and the Balanced Closeness approach. The first one assigns each base station randomly to the access routers of the access network while the second one selects K base stations and computes the nearest $N = |B| / |K|$ base stations to build $|K|$ groups to associate the access routers.

The DMM approach locates the distributed mobility anchors closer to mobile users with the aim of generating a flatter network. These anchors are responsible for managing signaling traffic. Due to the distribution of the nodes, DMM reduces in 20%, on average, the traffic bottlenecks that affect to the CMM approaches, providing performance improvements in the control plane. Moreover, the signaling cost is directly proportional to the $|K|$ value for both analyzed protocols. Thus, concerning the mobility management protocols, both solutions demonstrate a clear trend as the number of access routers increases. The proposed Link-Network Algorithm improves in both mobility management protocols reducing the signaling. In PMIP, the proposed algorithm reduces around 25% compared with Balanced Closeness and around 85% the random proposal. The last result is expected because the assignment of the base stations to the access router is a critical decision that can increase the signaling of the protocol, as shown in the analysis. In NB-DMM, the proposed algorithm reduces the signaling cost in around 30% compared with Balanced Closeness and around 86% with random assignment.

Figures 8 and 9 show the performance of the data plane. As could be observed, the packet delivery cost is greater in PMIP approach than in NB-DMM. This is produced because PMIP introduces the LMA that serves as an anchor to the MN. This produces suboptimal routing in the network and increase the packet delivery cost, and P_{cost} because a tunneling mechanism is introduced to forward data packets. In PMIP, the improvement applying the algorithm is not relevant due to this suboptimal routing, but in NB-DMM, the improvement of the proposed algorithm is around a 2% on average using Balanced Closeness and around a 7% with the random analysis. With these results, it can be concluded that the proposal, even improving the signaling of the mobility management protocols, can improve in a lesser extent the packet delivery protocol.

We can also see in Figures 8 and 9, when the number of access routers is increased, using the assignment algorithms based on clustering techniques, the P_{cost} begins to decrease with respect to lower $|K|$ values.

Figures 10 and 11 show the impact of the signaling in the delay introduced in the network. As could be observed the average delay introduced by the signaling decrease using the proposed Link-Network Algorithm in both scenarios, using PMIP and NB-DMM.

The average bandwidth used to obtain this measurement is around 3 Mbps for each mobile node. Using PMIP as the mobility management protocol, the improvement is around 28% when the Balanced Closeness algorithm is used and around 83% in the random proposal. As could be observed, this measurement is deeply connected with the signaling cost. In NB-DMM, the improvement is around 31% using the Balanced Closeness algorithm and around 85% using a random assignment.

All these numerical results are summarized in Table 3, which reflects the average and error of accumulated costs during all performed simulations. As shown in this Table 3, the overall delay introduced in the simulations is described. Consequently, with the results presented in Figures 10 and 11, the measurement coincides and presents a big delay introduced when the number of handovers is increased.

The results demonstrate that our proposed algorithm minimizes the impact on the total mobility cost and reduces the delay introduced by the signaling of the handovers. The benefits obtained are more significant in DMM when Link-Network assignment is used.

6. Conclusions and Future Works

This paper proposes a new way to improve the mobility management protocols that can affect positively to the latency of the network in 5G. The Link-Network Assignment Algorithm improves the mobility management protocols, centralized and distributed, reducing the signaling to manage the handovers, and maintain the reachability of the mobile node on the Internet. This mechanism also improves the packet delivery cost, especially in distributed mobility management protocols and the delay introduced by the signaling of the mobility management protocols, which will improve 5G's URLLC. The proposed algorithm has been compared favorably with others in terms of mobility costs (signaling cost, data packet delivery cost, and signaling delay), allowing the overall mobile network performance to be evaluated. Obtained results demonstrate that the LNA algorithm can successfully reduce the signaling cost by up to 86% compared with the baseline algorithm without penalizing the packet delivery cost that is also improved by up to 7%. This reduction in both metrics is one of the main contributions of this work. With these results, and taking into account, the expected increment of traffic expected for future mobile networks, our proposed mechanism offers significant gains for network operators to plan deployments for improving network performance for mobile users.

Future research in this direction would involve testing assignment algorithms based on other clustering mechanisms on different access network topologies. Moreover, some initialization techniques to find optimal centroids will need to be implemented in order to minimize the impact of base station assignment on the access network.

Notations

G:	Undirected graph of the access network
V:	Set of network nodes
E:	Set of network links
B:	Set of base stations

K: Set of access routers. Each access router is denoted by $\{k_j\}_{j \in K}$
N: Set of mobile nodes which around the network
x_{mr}^{ps}: The binary decision variable equal to 1 if base station m is assigned to the access router r and p is assigned to s, 0 otherwise
TC: Sum of the signalling cost and packet delivery cost
$C_u(\cdot)$: Signalling cost
$P_{cost}(\cdot)$: Packet delivery cost
$\delta(\cdot)$: Signalling delay
NT: Network topology
C: Set of all centroids calculated by k-means++ algorithm from the set of base stations (B)
D_{CKM}: Matrix of distances between centroids
D_{AR}: The distance matrix of topology access nodes
M_C: This array stores the Euclidean norm of all centroids
CC_{AR}: This array stores the closeness centrality of each access routers
MC: The highest centroid modulus value
cc: The minimum value of closeness centrality
d_c: Distance vector that indicates the distance between MC and all others
d_{ar}: Distance vector that stores the distance between cc and all others
$DictAssoc$: Dictionary with the final relation between base stations and access routers
h_{X-Y}: Hop distance between X and Y nodes
s_u: Size of the Proxy Binding Update message
$nActiveMAR$: Number of Mobility Access Routers with an active session anchored for a particular mobile node
s_d: Size of the data messages
s_t: Size of the tunnel header
$N_{p/s}$: Packet transmission rate per active flow
B_w: The mean bandwidth of the links.

Data Availability

The data supporting this work are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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