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Distributed mobility management based on centrality for dense 5G networks

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***Abstract*—This paper presents distributed mobility management techniques for 5G networks based on the *centrality* of the nodes in the network. This centrality concept is introduced for the 5G network as a mean for the definition of mobility anchors and the data forwarding nodes in the network. The corresponding distributed mobility management scheme is then simulated through simplified system level simulations. The performance of the proposed distributed mobility management is compared to that of legacy mobility management systems based on LTE and DMM. It is seen that the performance of the proposed system improves the performance of the legacy mobility management of about 14%.**

I. Introduction

Distributed mobility management is expected to play a key role in the latency optimization of the future 5G systems and networks [1]–[3].The mobility management of the current LTE communication system is essentially centralized in data and control planes [7]. In such centralized system, the data packets (data plane), intended to a given user terminal (UE), are transmitted to the source and/or target base stations during the user terminal handover through a single network entity known as (serving/packet data networks gateway (S/P-GW)) or "'mobility anchor" for the data plane. The *path* from the mobility anchor to the base station and the quality of service (QoS) parameters requested by the user terminal, (control plane) are determined by mobility management entity (MME) [7]. Thus there is also a central point for the management of the control plane during handover for the user terminal. The future 5G networks are expected to be 10 times denser than the legacy LTE heterogeneous networks, so the legacy centralized mobility management schemes will introduce higher handover latencies both for data and control plane signaling for these node densities [3]. This motivates the development of specific distributed mobility management schemes that will offload the core network from this extra handover signaling and improves the overall handover latencies of the $5G$ networks. Moreover, there is also a need for a scalable systems that can handle efficiently the addition of new nodes in the network with reduced MME and S/P-GW complexity. In the literature, distributed mobility management (DMM) was developed mainly for IP based mobility [1], [2], [8]. The basic principle of DMM is to allow each node of the network to act as data plane mobility anchor that is providing distant users with an access point to the internet. Each time a handover is performed for the user terminal, the new location of the user terminal is registered in the mobility anchor in order to forward the packets to the new location of the user terminal. The proxy mobile IP (P-MIP) scheme [12] is a example of this approach. The main drawback of this DMM approach is the introduction of important communication delay and overhead that is due to frequent location updates at the mobility anchor, especially for high traffic and node density. Thus, the control plane management of DMM is a key component for further optimizing the delay and overhead of this mobility management approach. One popular idea is the centralized control plane management of the DMM, also known as SDN based mobility management in the literature that was recently proposed in [1], [2] as a candidate for mobility management in 5G networks. The main advantage of this centralized control plane management of DMM is to allow the fast configuration of mobile anchors and the centralization of the location updates for the user terminals in the network. However, this approach may lack of scalability and need to be further improved to minimize the handover interruption time.This paper proposes such an optimization of the handover interruption time in the SDN-based DMM mobility management systems. The basic idea of the paper is to use *betweeness centrality* for ranking the nodes of the network [9]. The nodes with the highest betweeness centrality will be selected as mobility anchors for the user terminals of the network. These mobility anchors will be the closest nodes to the traffic or the nodes that are the most likely to be on any possible path in the network if a random walk of the UEs is assumed [9]. Thus, the betweeness centrality should depend on the measurements performed by the user terminals during the handover in the network. The proposed optimization is an implementation of SDN-based DMM where the SDN controller collects the handover measurements of the user terminals and calculate the betweeness centrality of the nodes. The main advantage of the proposed approach is its flexibility and scalability since this centrality may be transmitted to the nodes that can locally update the mobility anchors for the further adaptation to the traffic situation in the network. The outline of the paper is as follows: in the section II, collecting the handover measurements of the user terminals into a *neighborhood graph* is presented betweeness centrality calculation is described. Then, in the sections III-A, the simulation scenario used for the handover evaluation is presented. The simulation results are presented in the section III-B where the proposed SDN- based DMM is compared to the performance of the legacy LTE system and to DMM where the mobility anchors are chosen randomly, i.e. without any centrality metric. In the section IV we draw some conclusions and future work.

II. Centrality based optimization of SDN- DMM

A. Neighborhood graph

The 5G network is modeled as an ultra dense network (UDN) where the positions of the nodes are not planned and where the nodes densities is around 10 times higher than the legacy LTE networks densities. The user terminal traffic of the UDN is assumed to be spatially random and with intensity, i.e. average number of user terminals, higher than the traffic of the legacy LTE systems. The user terminals are able to measure periodically the received power from the nodes of the network and the received signal quality, expressed as signal to noise and interference ratio (SINR). Each user terminal transmit the measurements of its *neighboring nodes* to the control plane central point, i.e. SDN controller. The SDN- controller uses these combined measurements to build the *neighborhood graph* of the moving user terminals. The neighborhood graph is a graph structure where each node represents one node/base station of the UDN. Two nodes of the neighborhood graph are linked by an edge if user terminals attached to one node reports the other node with sufficient strength. For example, an edge links two nodes if the received power of the neighboring node of the user terminal is received with sufficient power or SINR. This is illustrated in the figure 1. The *neighborhood*

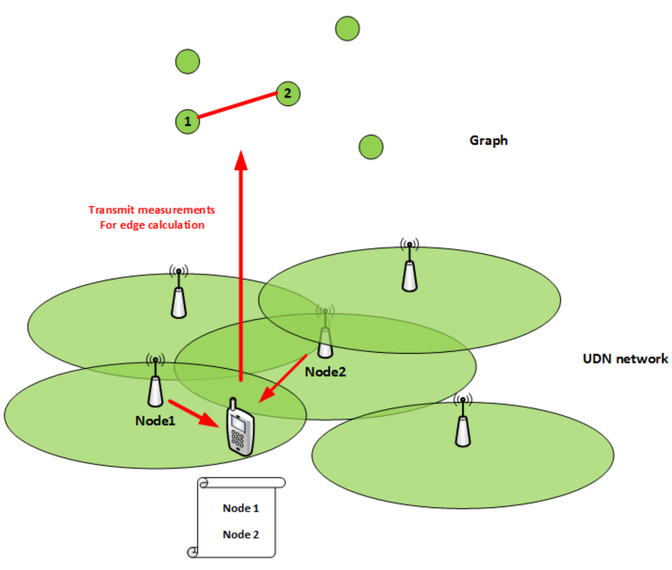

Fig. 1. Example of neighborhood graph

graph is used at the SDN controller to obtain future handover candidates for the user terminals. These handover candidates are located along paths of the graph. The *most probable* future handover candidate node is the defined as the node that is contributing to the maximum number of paths in the graph. The betweeness centrality of the node expresses basically the average contribution of the node to the shortest paths in the neighborhood graph. The section II-B describes the calculation of this centrality metric.

B. Betweeness centrality and handover latency

The betweeness centrality is directly linked to the number of *shortest paths* the node i is contributing in the neighborhood graph. A path in the neighborhood graph is defined as the sequence of nodes $P = \{i_1, i_2, i_3, ...i_N\}$ a user terminal is traversing during its mobility in the network. The distance of the path P may be defined as $d_P = \sum_{k=1}^{N} \tau_{i_k,i_{k+1}}$ where $\tau_{i_k,i_{k+1}}$ is the latency of the transmission from the node i_k to the i_{k+1} along the path P. The betweeness centrality for the node i is defined as the following :

$$C_B(i) = \sum_{s \neq t; s,t \neq i} \delta_{s,t}(i) \qquad (1)$$

The parameter $\delta_{s,t}(i)$ is defined as the number of *shortest paths* from the node s to the node t of the graph that are passing through the node i over the total number of shortest paths that are passing through the node i.

$$\delta_{s,t}(i) = \frac{N_{s,t}(i)}{N_{s,t}} \qquad (2)$$

$N_{s,t}(i)$ is the number of shortest paths between any couple of nodes (s, t) in the network that are passing by the node i and $N_{s,t}$ is the total number of shortest paths between the nodes s and t. The calculation of the betweeness centrality involves two steps that are performed at the SDN- controller :

- Count the number of shortest paths between any pair of nodes in the network $N_{s,t}$ and the number of shortest paths passing by the node i, $N_{s,t}(i)$.
- Accumulate the path dependencies $\delta_{s,t}(i)$ in order to obtain the betweeness centrality $C_B(i)$.

The counting step is achieved by using breadth first search (BFS) for unweighted neighborhood graph or Dijkstra search algorithm where the edges of the graph are weighted with the latency $\tau_{i_k,i_{k+1}}$ of the transmission between the nodes i_k and i_{k+1}. The details of the graph search techniques will not be detailed here but can be found in [9]. The accumulation step is performed either by summing the number of shortest paths obtained previously or by using the brands approximation [9] as the following.

$$\delta_s(i) = \sum_{w: i \in P_s\{w\}} \frac{N_{s,i}}{N_{s,w}} \left(1 + \delta_s(w)\right) \qquad (3)$$

$P_s\{w\}$ is defined as the predecessor set over the minimum distance path from the node s to w. The parameter $\delta_s(i) = \sum_{t \neq s} \delta_{s,t}(i)$ is defined as the accumulated path dependencies.

The equation (3) shows the possibility of a distributed implementation of the betweeness centrality calculation since the nodes of the network needs to exchanges their accumulated path dependencies $\delta_s(w)$ and the number of shortest paths $N_{s,i}$. The betweeness centrality of the node i is obtained as

$$C_B(i) = \sum_s \delta_s(i) \tag{4}$$

The centralities of the nodes are used to find the mobility anchors and the data forwarding nodes in the network. The data forwarding nodes are the nodes that are relaying the user plane data to the mobility anchors in the network. The moblity anchors are the nodes with the highest betweeness centrality in the network. In the case of unweighted graph, the nodes with maximum betweeness centrality is the closest in the sense of the minimum hop count to all the nodes of the neighborhood graph. For the neighborhood that is weighted with the packet transmission latencies, the mobility anchors are the nodes that are the closest in the sens of sum transmission latencies with all the nodes of the network. In the section III we propose an evaluation of the DMM system where the mobility anchors are chosen as the nodes with the maximum betweeness centrality in the neighborhood graph. All the other nodes, with medium/low betweeness centralities are considered as data forwarding nodes. The section III-A describes the simulation scenario that is used for the validation of the distributed mobility management scheme. The section III-B shows in detail the simulation results of the paper.

III. Simulations

A. Simulation scenario

The simulation scenario considered in this paper is a set of D base stations randomly deployed in a square region of 1 km^2. The deployment is outdoor where the radio parameters are described by the table I. A crowd of 300 user terminals is randomly dropped in the network coverage region where the base stations are deployed. The measurements from the crowd are used to build the neighborhood graph of the network. The betweeness centrality is calculated through the Brandes algorithm [10] where only hop count is considered as a path metric, i.e. we use BFS search for the path count step of the Brandes algorithm. The handover delay assumptions used in the simulations are standard handover delay assumptions, usually used in 3GPP evaluations [6], [5]. These simulation assumptions are recalled as :

TABLE I
Simulation Parameters

Parameter	Value
Carrier	2GHz
Pathloss(dB)	$104 + 36.7log10(r)$
Antenna Gain	5dBi
Body loss	6dB
Maximum transmit power	20dBm
Noise factor	9dB
Shadowing	no shadowing

- 2 ms latency for the signaling over the Uu interface,i.e. the communications between the user terminals and the base station they are attached to.
- 5ms for S1/X2 signaling, i.e. the LTE wired signaling between the base stations for handover preparation and packet forwarding.
- 20ms for backhaul reconfiguration

The figure 2 illustrate the handover timing diagram of a user terminal that is performing handover from source base station (S-eNB) to a target base station (T-eNB) where the distributed mobility is considered, i.e. the source and target base stations are communicating with the mobility anchor . From the figure,

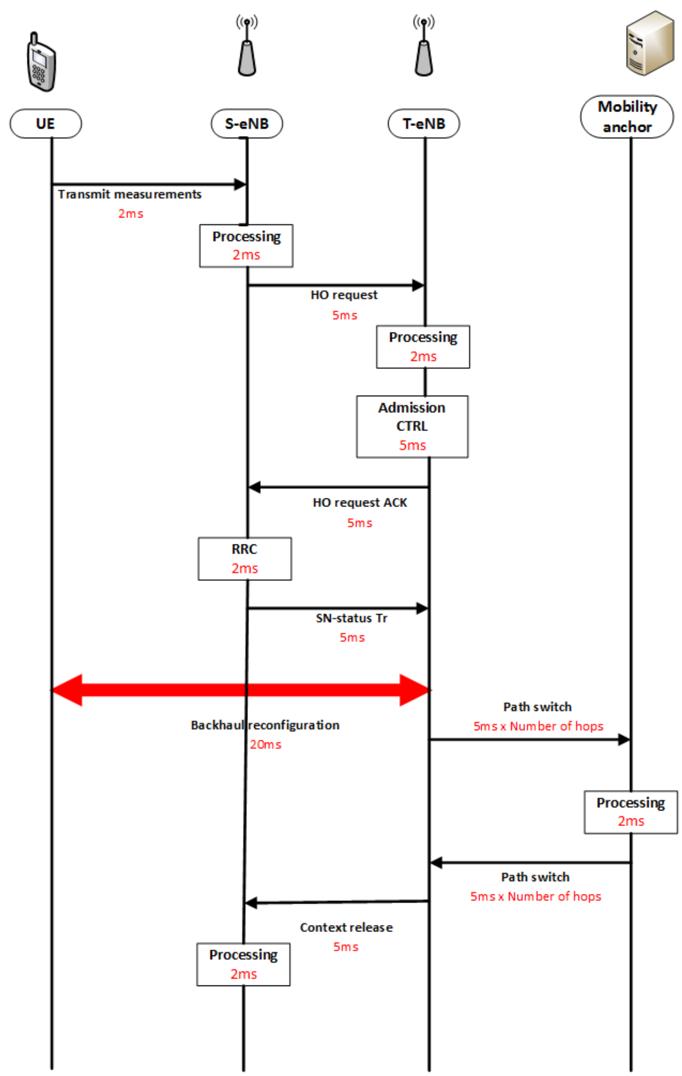

Fig. 2. timing diagram of handover in DMM setting

it is possible to count the overall handover latency Δ for a given user terminal as

$$\Delta(ms) = 57 + 10N \tag{5}$$

Where N is the number of hops from the target base station (T-eNB) to the closest mobility anchor. The simulation results presented in the section III-B evaluate these handover latencies for 1000 independent Monte-Carlo runs. The betweeness centralities are calculated through the Brandes algorithm and the mobility anchors are determined as the nodes with maximum betweeness centralities. The number of mobility anchors is obtained as N_a and the performance of the DMM scheme is compared with the performance of DMM with N_a randomly chosen mobility anchors are considered. These mobility anchors are not chosen as the most central nodes in the network.

B. Simulation results

In this section we present simulation results to show that the proposed centrality based DMM optimizes the handover latencies of the system. We will compare these handover latencies with the legacy LTE handover latencies and the random DMM approach described previously where the mobility anchors are chosen without taking the base stations centralities into account. The figure 3, is showing the standard timing diagram of the legacy LTE handover as used in the evaluations of 3GPP [5]. The overall handover latency of the legacy LTE system is evaluated as $\Delta_0 = 86$ms. This value will be used as the baseline handover latency for the evaluations of the paper. The figure 4 illustrates the neighborhood graph for the simulation scenario of a single drop of $D = 60$ nodes and a crowd of 300 user terminals in a region of 1 km ^{2}. The neighborhood graph is obtained from the received power measurements of a majority of user terminals. The centralities of the nodes are calculated through the Brandes algorithm and shown in blue red and magenta colors. Mobility anchors are the nodes with the highest centrality in the deployment scenario, shown in red color in the figure. The nodes with the lowest centrality are the blue nodes in the figure while the nodes with intermediate centralities are the nodes with magenta color. The figure 4 show that there is 4 mobility anchors for the simulated neighborhood graph which correspond to 6 % of the total number of nodes in the deployment. The figure 5 shows the cumulative distributed function (CDF) of the handover latency for distributed mobility management system with a density of D=15 and 30 nodes. The mobility anchors are chosen randomly for the baseline distributed mobility system. The proposed optimization of the DMM chose the mobility anchors as the nodes with the highest betweeness centrality in the deployment. CDF are obtained from the simulation of 1000 independent Monte-Carlo runs of the positions of the base stations and a crowd of 300 user terminals in the coverage region. Two observations can be made from the results of the figure 5. The first observation is that the average handover latencies for the DMM are lower than the baseline handover latency legacy LTE systems. The best performance improvement with respect to the legacy LTE handover latency is around 13% for the density of D=15 nodes and 7% for a density of D=30 nodes. DMM systems with mobility anchors chosen as the nodes with the maximum betweeness centrality are showing the best performance, i.e. improving the performance of the DMM with

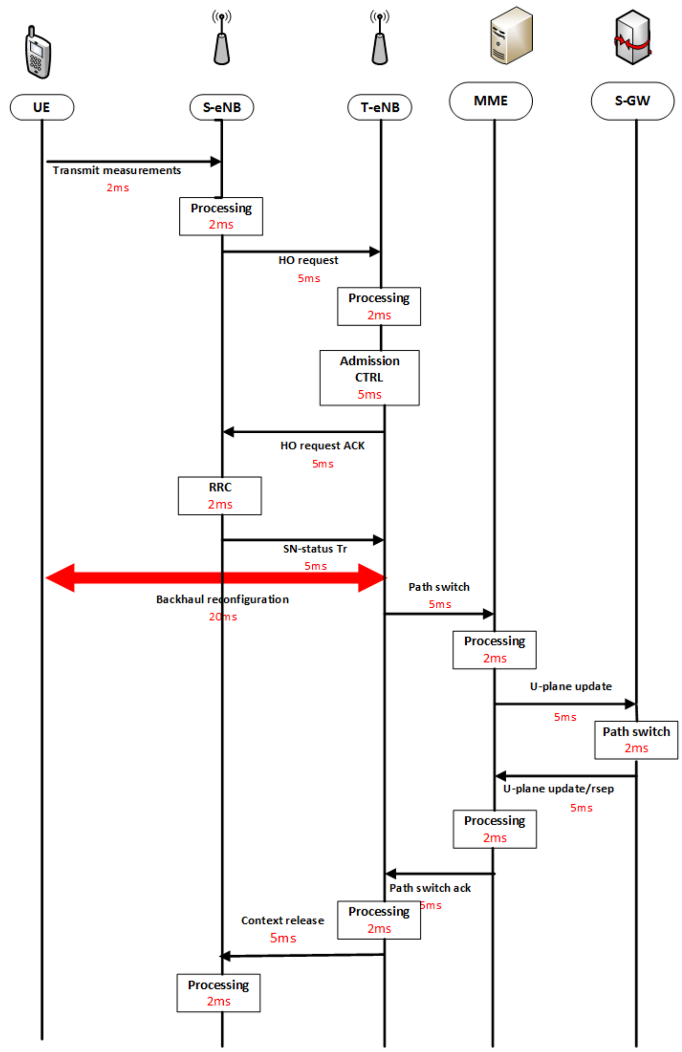

Fig. 3. Timing diagram of handover for legacy LTE handover

random anchors choice of 2% for the density of D=15 nodes and 4% for a density of D=30 nodes. The figure 6 shows the evolution of the average handover latencies for random and centrality based DMM with respect to the density of the nodes. We have considered node densities up to 60 nodes. The results of the figure 6 are showing that the average latency of the centrality based DMM is better than the performance of DMM with random anchoring. The improvement is around 4% for high node densities (D=60) and around 2% for low node densities. When comparing the performance with the the baseline LTE handover latency, it is seen that DMM improves the legacy handover latency of 11% at maximum for low node densities for random allocation of the anchors. Centrality based anchor choice is improving the baseline handover latency of 13 % at maximum for low node densities. For high node densities, i.e. (D=60), centrality based DMM improves the handover latencies of 10% while random mobility anchors choice improves the legacy system performance of only 6%. This result is showing that the maximum betweeness centrality

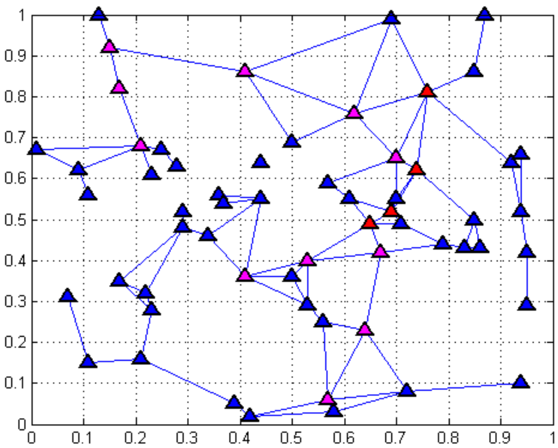

Fig. 4. Neighborhood graph and betweeness centralities

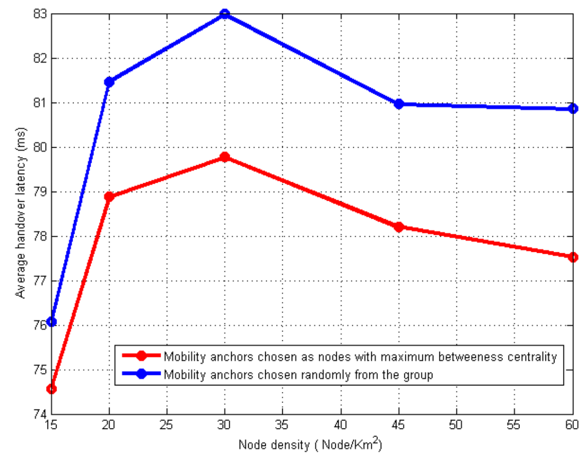

Fig. 6. Evolution of the average handover latency with respect to node density

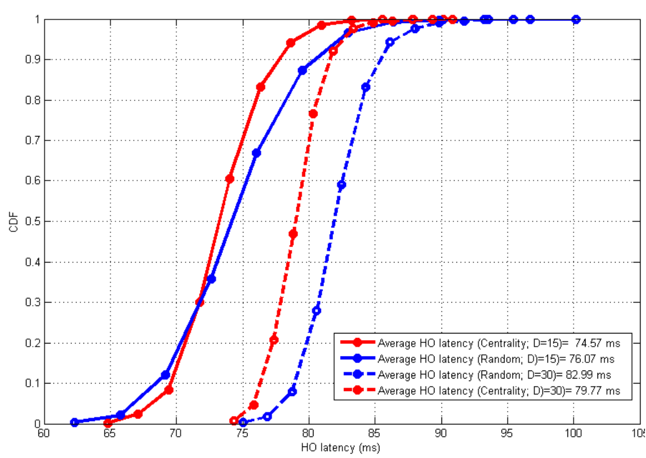

Fig. 5. CDF of handover latencies

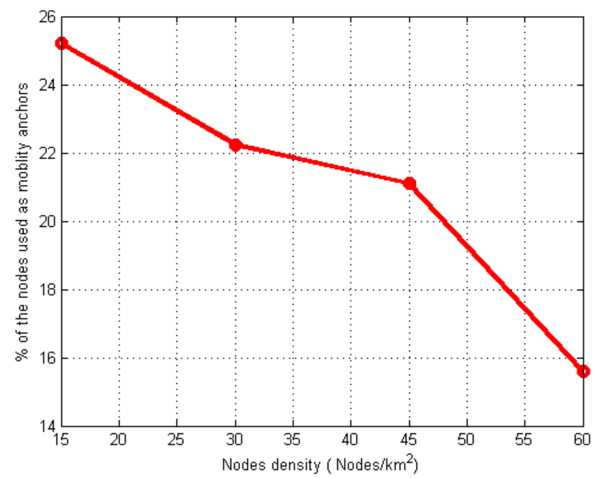

Fig. 7. Evolution of the average handover latency with respect to node density

allocation of the mobility anchors is well suited for ultra dense networks that will be the basic component of 5G networks. The figure 7 shows the evolution of the average number of mobility anchors for the centrality based DMM. The number of the nodes used as mobility anchors is expressed as a percentage of the total nodes D of the deployment. The results are showing that when the density of the nodes is low there is on the average 25% of the nodes that are mobility anchors for the deployment scenario. When the density of the nodes is increasing the number of mobility anchors is on the average 14% which gives on the average 9 nodes that are serving as mobility anchors for a density of $D = 60$ nodes. These results are interesting, since it shows that for a large and ultra dense network, the proposed DMM improves the handover latency with a low number of anchors in the network. This minimizes inter- anchor handover that introduces high latencies in the system.

IV. Conclusion

In this paper we presented and discussed new strategies for distributed mobility management (DMM) in typical ultra dense 5G networks deployments. The DMM system is consisting of performing the anchoring of the data plane closer to the nodes instead of the conventional mobility anchoring in the serving gateway located in the core network [7]. The basic question we have considered in this paper is how to choose these mobility anchoring nodes such as to optimize the performance in terms of handover latency. It is proposed in this paper to identify these mobility anchors as the nodes with the maximum betweeness centrality in network. This choice improves the performance of the legacy LTE handover of 13%. The maximum betweness centrality DMM system is shown to improve the performance of the legacy LTE system of 10% in the case of high density deployments while random mobility anchoring improves the same scenario of only 6%. The average number of anchors in the deployment is around 14% of the nodes in high density deployments.

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