Handover Management in Software-Defined Ultra-Dense 5G Networks

Tuğçe Bilen, Berk Canberk, and Kaushik R. Chowdhury

Abstract

Ultra-densification is a key approach aimed at satisfying high data traffic in next-generation 5G networks. However, the high number of small cell eNB deployments in such ultra-dense networks (UDNs) may result in unnecessary, frequent, and back-and-forth handovers, with additional problems related to increased delay and total failure of the handoff process. Additionally, due to the separation of control and data signaling in 5G technology, the handover operation must be executed in both tiers. In this article, we propose an SDN-based mobility and available resource estimation strategy to solve the handover delay problem. Here, we estimate the neighbor eNB transition probabilities of the mobile node and their available resource probabilities by using a Markov chain formulation. This allows a mathematically elegant framework to select the optimal eNBs and then assign these to mobile nodes virtually, with all connections completed through the use of OpenFlow tables. Finally, we compare the conventional LTE and our proposed handover strategies by analyzing the observed delays according to the densification ratio parameter. Also, we analyze the handover failure ratios of both strategies according to the user number. Results reveal that the proposed strategy reduces the handover delay and failures by 52 and 21 percent compared to the conventional approach.

Introduction

The unprecedented growth in the number of mobile nodes, connected devices, and data traffic lead to the dense deployment of fifth generation (5G) networks. Such an ultra-dense network (UDN) is created by installing a high number of small cells with less coverage inside the deployment area of a single macrocell. In this way, a greater number of simultaneous user connections are enabled by the small cells. Therefore, the capacity, coverage, spectrum efficiency, and data rates are significantly increased compared to the case of macrocell operating alone. On the other hand, the migration to this dense architecture increases the interference and energy consumption of the network. As a solution to these problems, a separated architecture for the control and data planes is used in 5G networks. Accordingly, the small cells and macrocells handle the data and control signaling (e.g., radio resource control [RRC]) traffic, respectively [1]. Thus, for satisfying the requirements of the future UDNs seamlessly, it is necessary to implement several key modifications in the 5G network architecture.

Besides the above-mentioned problems, the mobility related signaling overhead (e.g., radio resource management [RRM] measurements/reporting), increased handover delay, failures, and rates are other observed problems in the ultra-dense 5G networks as shown in Fig. 1. Accordingly, 5G networks require a novel and accurate mobility management method for dealing with these challenges. The separated control and data channels connected to the different macrocells and small cells that function in two different tiers must be synchronously handled during mobility management. Therefore, in addition to the architectural changes (e.g., increased small cell numbers, changing coverage areas, separated channels), the ultra-dense 5G networks necessitate innovations in the management of the network.

Handover Related Challenges in UDNs

While there are many open challenges in designing a UDN, our focus here is on identifying a solution to the problem of *handover* management during mobility. Understandably, the high number of small cell and mobile node deployments on the UDN increase the handover count [2]. This situation can result in a large accumulation of unnecessary and frequent handovers. Specifically, if these frequent handovers occur among the target and presently serving cells continuously, a back-and-forth signaling storm (the so-called *ping-pong* handover problem) is observed. Thus, network resources and energy get consumed at more than the usual rate because of the control traffic spike, which can also increase the risk of handover failure. Moreover, the mobility related signaling overhead between the mobile node, and serving and target eNBs is increased [3].

To solve these problems, different mobility management algorithms are proposed in the current literature. In [4], a handover mechanism with modified signaling procedure is proposed to solve the unnecessary handover problem. Also, [5] proposes a state-dependent handover decision algorithm to reduce the handover failure rate and improve the small cell utilization. Moreover, [6] proposes a cooperation-based cell clustering scheme to decrease the frequent handovers in dense small cell networks. Additionally, [7] investigates the relation between handover failure and ping-pong rates during the handover process. These works solve only some specific handover problems shown in Fig. 1.

Also, practical delays observed during the handover procedure, and the unique scenarios emerging from the data/control channel separated architecture of 5G networks are not considered in these works. On the other hand, in the

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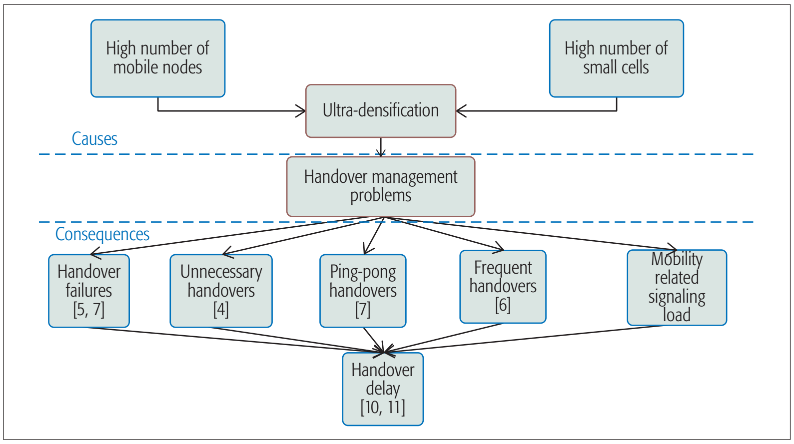

FIGURE 1. UDN handover problem tree.

special 5G architecture control, data channels are managed by the different macrocells and small cells. Accordingly, during mobility management, these two different cell connections should be handled at the same time. Moreover, the handover delay is cumulative if the same device undergoes multiple handovers, resulting in a severe impairment to the end-user experience. Therefore, we believe that minimizing the handover delay is a key issue in the design of future ultra-dense 5G networks. Additionally, any delay management scheme for handovers in 5G networks must be executed in two tiers, for both control and data channels, which has not been investigated so far.

In Third Generation Partnership Project (3GPP) LTE handover standards [8] (based on the X2 interface), in the handover preparation phase, mobile nodes measure the RRM parameters, such as reference signal received power (RSRP) and reference signal received quality (RSRQ), of a high number of evolved node Bs (eNBs) to choose the eNBs that provide the triggering condition (e.g., RSRP higher than a threshold) (so-called searching process). Then the mobile node transfers these measurement reports to the serving eNB. The serving eNB decides the handover by using these results, and the handover request is sent to the target eNB. According to the admission control results of the target eNB, the handover acknowledgment message is sent to the serving eNB as summarized in Fig. 2b. The searching process and resulting mobility related signaling overhead increase the handover delay [9]. More specifically, this handover delay observed in the handover preparation phase to access the best target eNB becomes cumulative in UDNs.

Each small cell receives a large number of handover requests, followed by the local execution of the admission control algorithm for each accepted request. If these incoming handover request arrival rates are greater than the admission control rate, a high number of the requests wait in the queue of the target eNB. Also, the excessively long time to empty its queue means that the requests wait idly in the queue, and this situation further contributes to delays.

To alleviate the above issues, specific 5G architecture requirements arising from the densification of mobile nodes and small cells should be considered during the mobility management in 5G UDN architecture. Unlike the conventional mechanisms, different approaches based on software-defined networks (SDNs) and stochastic geometry concepts are proposed for solving the handover delay problem in [10, 11]. However, these works do not consider an admission control mechanism to estimate available resources in the target eNB.

Article Contributions

We propose a novel Markov-chain-based and SDN-enabled handover management strategy for ultra-dense 5G networks. The main aim of this strategy is to choose and assign the most optimal eNBs to the OpenFlow tables of the mobile nodes *virtually* before the need for an actual connection. The main contributions of this approach can be listed as follows:

- We define a controller-driven scenario that incorporates mobility management and admission control modules. The mobility management module includes the eNB transition probability estimation and eNB selection engines.
- The transition probabilities of the mobile nodes are estimated with the Markov chain in the eNB transition probability estimation engine. Accordingly, the memoryless feature of this Markov chain helps us to show that the next movement of the mobile node is only dependent on the current state.
- In the admission control module, we optimize the available resources of each eNB through the predictions of the Markov chain model. In this way, the available resource probabilities in each eNB are found without complex admission control algorithms.
- We propose a dual-track estimation and allocation plan for the control and data channels separately, so as to ensure that both of these selections jointly influence the macrocell and small cell configurations.

The rest of the article is organized as follows. First, the proposed system model and network architecture are presented, followed by the proposed handover management approach. Then the delays and handover failures of the standard LTE and proposed handover mechanisms are evaluated. Last, the article is concluded, followed by future directions.

5G Network Architecture and Assumptions

The proposed SDN-based ultra-dense 5G network architecture, shown in Fig. 3, consists of the centralized controller, and the high number of small cells and mobile nodes in two separate planes (control and data planes). Details of these planes are explained below.

Control Plane

In the control plane, as shown in Fig. 3, we define a new controller with two unique modules: the *mobility management module* and *admission control module*. Also, the mobility management module includes the proposed eNB transition probability estimation engine and eNB selection engine. This controller governs the dummy small cells and mobile nodes in the data plane for the mobility management. Moreover, the controller can communicate with the mobility management entity (MME) and home subscriber server (HSS) components of LTE to handle the handover pro-

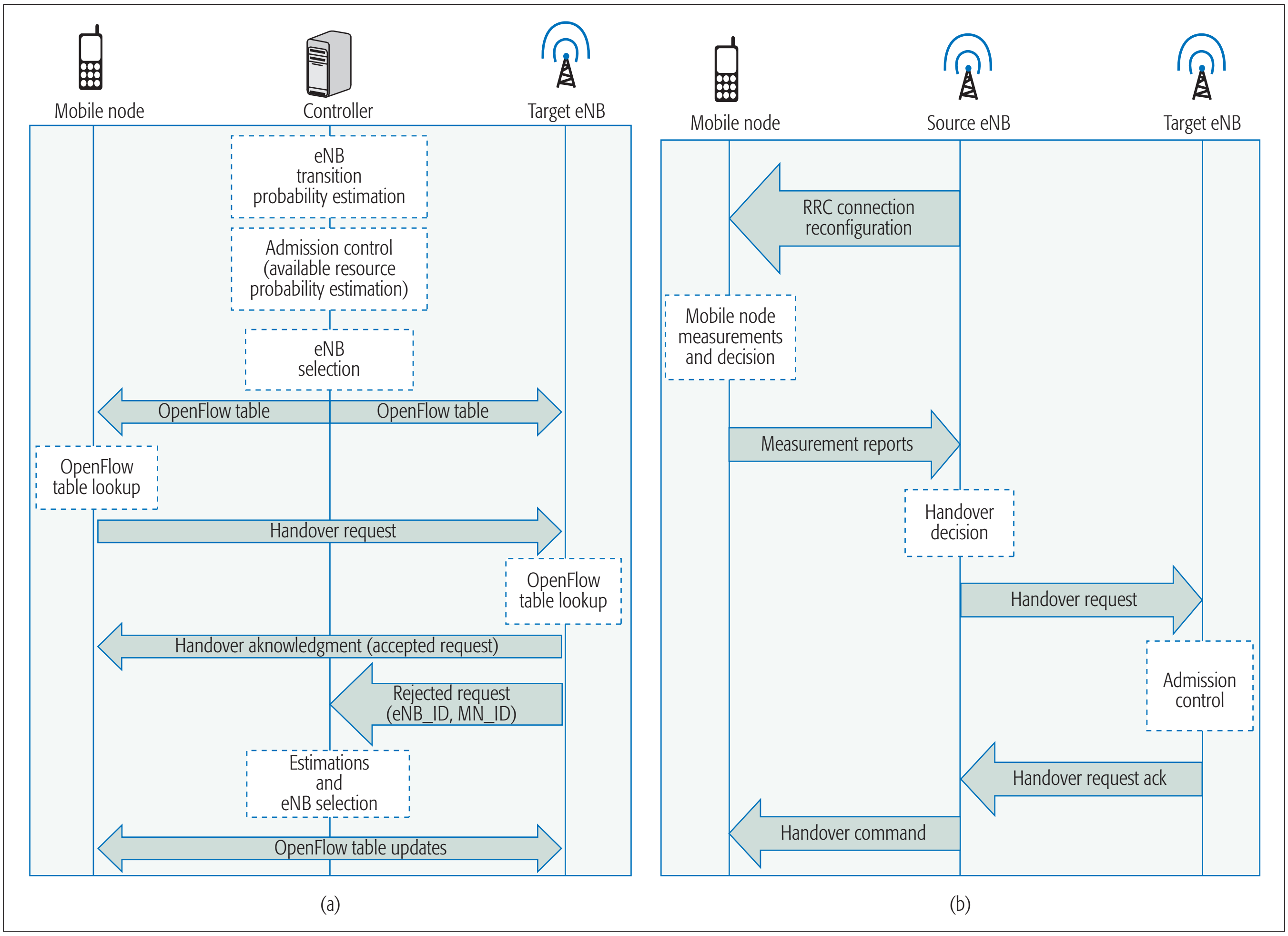

FIGURE 2. Handover procedure flow diagrams (handover preparation phases): a) proposed handover procedure; b) conventional LTE handover procedure (Rel. 12) [8].

cedure. In this way, the controller can obtain the required mobility related information (i.e., mobile node subscription information, mobile identification and addressing, tracking area updates). The mobile node id (*MN_ID*) and eNB id (*eNB_ID*) parameters are used in the controller for each of these mobile nodes and small cells.

Data Plane

The ultra-dense data plane consists of a high number of dummy small cells and mobile nodes. To show the densification level of the data plane, the following three parameters are defined [12]:

- *Small cell densification level:* shows the small cell number per unit area; represented by λ_S
- *Mobile node densification level:* represents the number of mobile nodes per unit area; given by λ_{MN}
- *Densification ratio:* shows the densification level of the network; found as $\tau = \lambda_S/\lambda_{MN}$

The communication among the controller and data plane are executed with the help of the *OpenFlow* protocol and OpenFlow tables. Therefore, the decisions of the controller are transferred to the OpenFlow tables of the mobile nodes and small cells through the OpenFlow protocol. In the OpenFlow table, a flow entry consists of the *priority*, *counters*, *instructions*, *timeouts*, *cookies*, *and match fields* [13] In the proposed approach, we utilize these OpenFlow tables for the handover decision different from the usual case. For this reason, the controller adds the *MN_ID* parameter to the small cell OpenFlow table match field. Also, the *eNB_ID* and sojourn time (t_{sj}) parameters are inserted into the mobile node OpenFlow table match and timeout fields by the controller.

Proposed Handover Management Approach

General Handover Procedure

To identify the proposed mobility management strategy in ultra-dense 5G networks, the general system procedure is summarized in Fig. 2a. This proposed handover management strategy can be explained as follows.

•In the proposed approach, eNBs on the network can have hexagonal architecture and six neighbor eNBs. Accordingly, a mobile node that exists in one of the eNBs has seven (six neighbor cells and one current cell) different neighbor cell transition probabilities. In this article, these transition probabilities are found with the Markov chain model. Moreover, if cell architectures are irregular with inconstant neighbor cell numbers, the controller can utilize the automatic neighbor relation (ANR) function of the eNBs. With the help of the neighbor removal and detection functions of the ANR, the neighbor relation tables of the eNBs are updated. Accordingly, the controller reaches the valid neighbor relations of the eNBs from

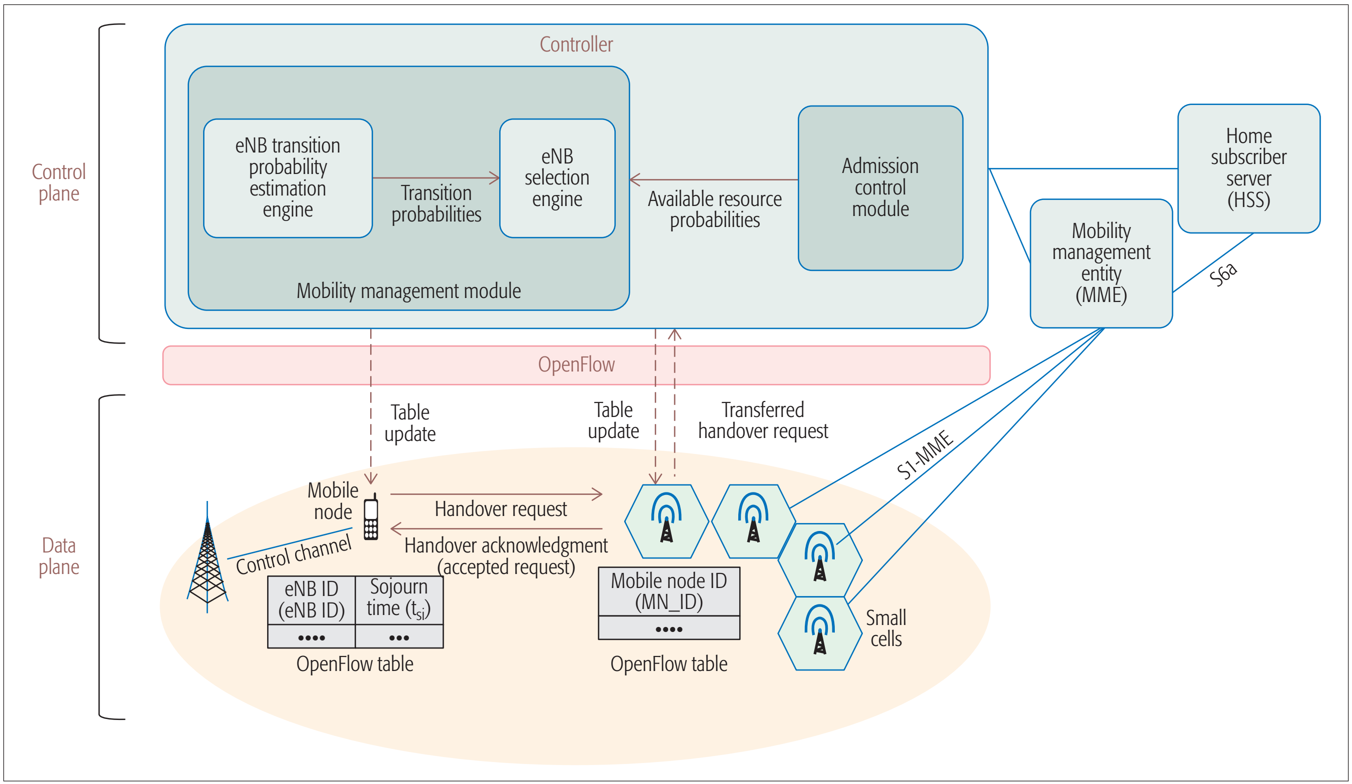

FIGURE 3. The proposed network architecture.

these tables. Then the transition probabilities are found for these neighbor cells by using the Markov chain model.

•After estimating the transition probabilities for the neighbor eNBs, available resource probabilities of these neighbor eNBs are estimated by using the Markov chain in the admission control module. Thus, the states of these Markov chains represent the available resource numbers of the corresponding neighbor eNBs.

•According to the outcomes of the above procedures, the next eNB is estimated and assigned virtually to the mobile node before the movement. Therefore, the estimated *eNB_ID* is transferred to the OpenFlow table of the mobile node. table of the corresponding eNB. Additionally, the sojourn time (t_{sj}) on this eNB is calculated and added to the OpenFlow table of the mobile node. All of the aforementioned procedures are executed for all eNBs located on the movement path of the mobile node.

•If the sojourn time (t_{sj}) in the current eNB expires, the mobile node checks the OpenFlow table to find the following eNB. Thus, as shown in Fig. 3, the mobile node sends a handover request to the found target eNB. Here, the communication among the mobile node and target eNB is executed with the random access channel (RACH). In LTE, the RACH is used by the mobile node to initiate the session with a random access preamble during the first step of the attach procedure. Also, this preamble includes the *MN_ID*. Then the target eNB controls the OpenFlow table to find this incoming *MN_ID*. If this *MN_ID* is included in the table, handover acknowledgment is sent to the mobile node. This acknowledgment indicates that the handover request is accepted by the eNB. Then the attach procedure continues between the mobile node and eNB with the corresponding message sequence as downlink shared channel (DL-SCH), uplink shared channel (UL-SCH). Although we do not give additional details about RRC connection setup and completion phases in this article, we are investigating the delays observed in the handover preparation phase. If the *MN_ID* is not found, this request is transferred to the controller. The controller updates the OpenFlow tables accordingly. The details of these procedures are explained in the following subsection.

Controller Modules

The centralized controller consists of the admission control module and mobility management module. The details of these modules are explained here.

Admission Control Module: In this module, the available resources in each neighbor eNB are modeled and estimated using the proposed Markov chain model.The resource number represents the simultaneous connection capacity of the corresponding eNB, and the available resource number indicates the remaining amount of the total connection capacity. Accordingly, the details of the proposed Markov chain model to find these available resource probabilities can be explained as follows:

- Each neighbor eNB is modeled using the Markov chain and $M\backslash M\backslash 1$ queueing system. Accordingly, the states of this Markov chain represent the available resource number in the corresponding eNB. Also, P_i represents the probability of i available resources in the eNB. As an example, P_2 show that there are two available resources in the corresponding eNB.

- To model the resources of the eNBs, we assume that each eNB has N resources initially. This means that the simultaneous connection capacity of the eNB is N. Accordingly, if a connection is received by the eNB, the resource number is decreased by 1. Also, the resource number of the eNB is increased by 1 for each terminating connection.
- λ_i and μ_i represent the call arrival and termination rates of the corresponding eNB with $\lambda_i \leq \mu_i$, $\forall\, i \in 1, 2, \ldots, n$.

Here, P_0 represents the probability of no available resource in the corresponding eNB, and it is found by using the following equation:

$$P_0 = \frac{1}{1 + \sum_{i=1}^{\infty} \prod_{i=1}^{N} \frac{\lambda_{i-1}}{\mu_i}}, \forall i \in 1,2,\ldots,7 \quad (1)$$

Thus, $1 - P_0$ shows the available resource probability of the neighbor eNB. This value is calculated for each of the neighbor eNBs with different λ_i and μ_i values. Therefore, if the eNB has a large number of available resources, the available resource probability of this eNB is increased. Otherwise, the value of the available resource probability is small, and the corresponding eNB becomes congested. Accordingly, selection of these eNBs accumulates the observed handover delay and failures. Moreover, these obtained results for each neighbor eNB are transferred to the eNB selection engine of the mobility management module.

Mobility Management Module: This module consists of the eNB transition probability estimation engine and eNB selection engine. The details of these engines can be explained as follows.

eNB Transition Probability Estimation Engine: The movements of the mobile nodes generally are not executed as random, and the mobility of these nodes can be studied by using different models [14]. Accordingly, in this article, the neighbor eNBs with the high transition probabilities are determined in the eNB transition probability estimation engine using the Markov model. To find these transition probabilities, we first require the neighbor eNB list of the corresponding cell. In this article, we investigate the neighbor eNBs of the corresponding eNB for the hexagonal and irregular cell architectures as explained below.

Neighbor eNB Determination for the Hexagonal Cells: In this situation, all eNBs have six neighbors with stable modes. This means that each eNB is always active without entering the sleep mode. Also, the controller keeps this stable topology information to detect the neighbor eNBs of the corresponding cell. Accordingly, if cells have hexagonal architecture, the mobile nodes on each cell have seven (six neighbor cells and one current cell) different transition probabilities because of the cell architecture. Accordingly, these cell transitions can be modeled by using a Markov chain as shown in Fig. 4. The states of this Markov chain represent the neighbor cells of the mobile nodes. Therefore, state transitions represent the physical movement of the mobile node to the corresponding neighbor cell with probability P_i. In this way, the transition probabilities for all the neighbor cells are estimated. Then the eNBs with the highest transition probabilities are transferred to the eNB selection engine with the calculated probabilities. Additionally, the sojourn time of the mobile node in the chosen eNB is calculated based on the equations in [15].

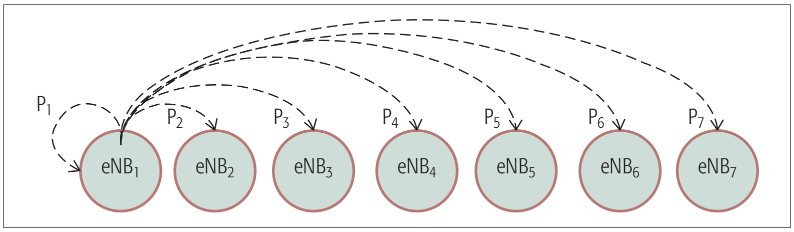

FIGURE 4. Markov chain for the transition probabilities. (Hexagonal architecture).

Number of macrocells/small cells	25/50–500
Number of mobile nodes	125–1250
Densification ratio (τ)	0.2–2
Bandwidth (MHz)	10
Resource number	50
Tx power for macrocells/small cells (dBm)	46/30
Mobile node speed (km/h)	10–100
Radius of macrocells (km)/small cells (m)	1/200
Antenna height for macrocell (m)/small cell (m)	25/10
Carrier frequency for macrocell/small cell (GHz)	2/3.5

TABLE 1. Simulation parameters.

Neighbor eNB Determination for the Irregular Cells: In this situation, each cell can have a different number of neighbor eNBs with variable modes. This means that each neighbor eNB can enter the sleep mode for power efficiency, which changes the number of active eNBs of the corresponding cell. Therefore, if cells have irregular architectures with variable neighbor cell numbers, the valid neighbors of the eNBs are reached with the help of the LTE ANR function of the eNBs. Each eNB has a neighbor relation table (NRT), and this table is managed by the ANR function. According to the RRC measurement requests/reports, the entries can add or remove to/from the NRT. Accordingly, the controller can utilize the NRTs of the eNBs to reach the valid neighbor lists of eNBs. Then the transition probabilities of the corresponding eNB are estimated for these valid neighbor cells by using a Markov chain as in the hexagonal cell architecture. Detailed information about the 3GPP ANR function can be found in [16].

eNB Selection Engine: In this engine, we have two different probabilities for each neighbor eNB, which are the transition and available resource probabilities. To select the most optimal eNB, these transition and available resource probabilities are multiplied for each neighbor eNB. Accordingly, each neighbor eNB has one selection probability for the mobile node. Among these selection probabilities, the eNB with the higher value is selected and assigned to the mobile node OpenFlow table virtually. Also, this mobile node is assigned to the OpenFlow table of the selected eNB. Furthermore, all of these procedures are executed on each

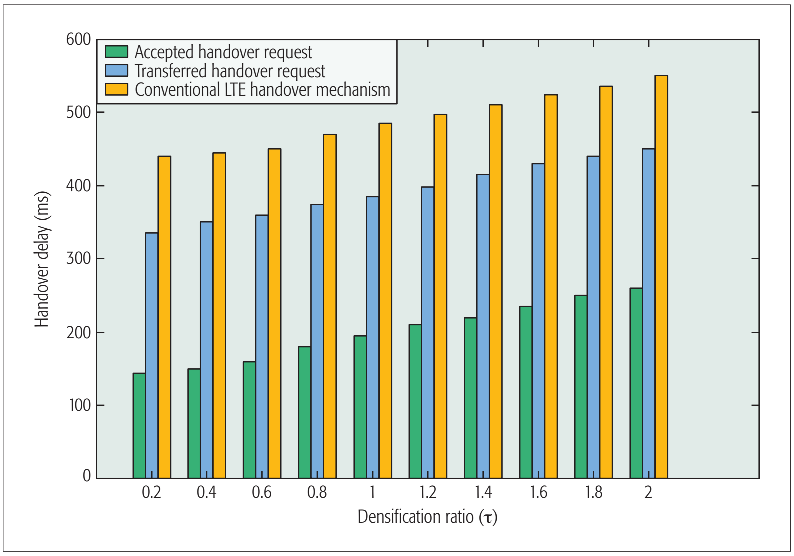

FIGURE 5. Delay analysis according to densification ratio.

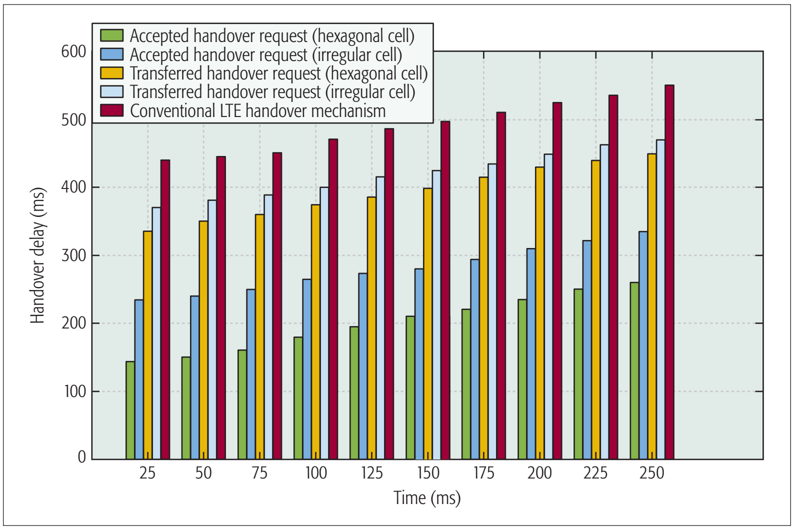

FIGURE 6. Delay analysis according to time.

of the eNBs which are located on the route of the mobile node. Furthermore, especially in 5G technology, all of these procedures should be executed to find the optimal macrocell for the control channels.

Performance Evaluation

The performance of the proposed approach is evaluated on the MATLAB-Simulink© environment. The details of the parameters used in simulations are given in Table 1.

In our simulations, first, handover delay is measured according to the densification ratio parameter for the proposed handover approach and the conventional LTE handover procedure. Also, the performance of the proposed approach is analyzed in two parts as accepted and transferred handover requests. Then the delays of the proposed and conventional handover procedures are investigated according to the time for the hexagonal and irregular cell architectures. Also, the handover failure rates of the proposed and conventional mechanisms are analyzed according to the increased user number. These simulation results are explained in the following subsections with details.

Delay Analysis According to the Densification Ratio

We evaluate the delays of the proposed and conventional handover approaches according to the different densification ratio (τ) values to indicate the effects of network densification level on the handover delay. As mentioned above, there are two parameters that affect the τ: the mobile node and small cell numbers. Accordingly, here we take the small cell number as constant with increasing number of mobile nodes. In this situation, waiting time in the queue increases with the densification level of the mobile nodes in the conventional handover mechanism. On the other hand, in the proposed approach, handover count increases because of the growing number of OpenFlow table entries. This observed delay is less than the conventional mechanism. Therefore, as shown in Fig. 5, we observe almost 52 and 24 percent fewer handover delays in the proposed approach during the accepted and transferred requests, respectively, compared to the conventional mechanism.

Delay Analysis According to Time

The delay of the proposed approach is investigated for the hexagonal and irregular cell architectures according to the time parameter. In addition to the hexagonal cell architecture evaluation results, we analyze the handover delay for irregular cells. In this situation, deployed eNBs can have different neighbor cell numbers. Additionally, the neighbor cell numbers of the eNBs do not remain constant because of the added, removed, and sleeping eNBs.

In this situation, as shown in Fig. 6, the handover delays of the hexagonal cell architecture during the accepted and transferred requests are 25 and 12 percent less than the delay of the irregular cell architecture, respectively. Moreover, the handover delay observed during the irregular cell architecture is almost 20 percent less than the delay of the conventional mechanism.

Handover Failure Analysis According to User Number

We also analyze the handover failure ratios of the proposed and conventional approaches according to the increased user number. Accordingly, in two strategies, the number of handover failures is divided by the total handover number to find the handover failure ratio. As shown in Fig. 7, the handover failure ratios of the proposed approach during the accepted and transferred requests are 21 and 18 percent less than the conventional mechanism, respectively.

Conclusion

Ultra-densification with a high number of small cells is one of the crucial approaches to satisfy the capacity requirements of the future wireless 5G networks. In this article, we propose a Markov-chain-based handover management strategy for software-defined ultra-dense 5G networks that selects the most optimal eNBs and assigns these to the mobile node virtually. All of the operations are handled by the controller, and data plane devices are notified with the help of the OpenFlow tables. Moreover, according to the simulation results, the proposed approach during the accepted handover requests has 52 and 24 percent fewer delays with respect to the densification ratio parameter compared to the conventional LTE handover procedure, respectively.

Future Directions

In this article, we investigate the handover delay problem caused by the searching process and the resulting mobility related signaling load in ultra-dense 5G networks. In addition to these factors, the increased ping-pong, unnecessary, and frequent handover rates aggravate the observed handover delay problem. As future work, we plan to examine the effects of these problems on handover delay and the eventual benefits of reducing such events.

Acknowledgments

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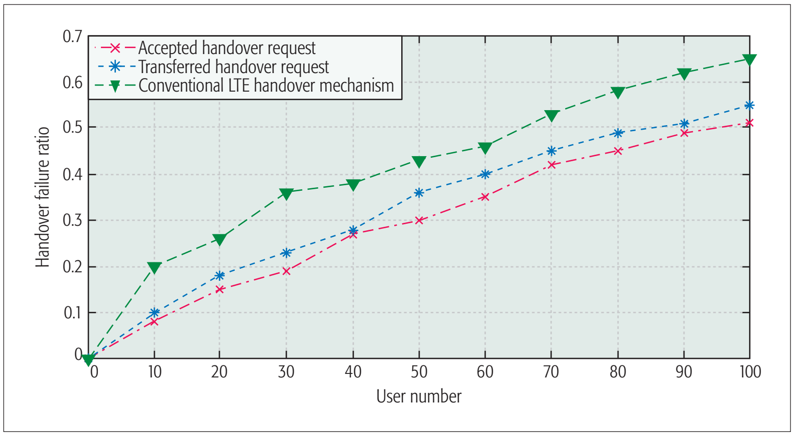

FIGURE 7. Handover failure analysis according to user number.

Biographies

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