SDN-based Local Mobility Management with X2-interface in Femtocell Networks

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***Abstract*—Femtocell technology has been recognized as a potential solution to face the explosive growth of mobile broadband by boosting the spectral efficiency and coverage area. Femtocells simultaneously bring challenges to provide an optimized and seamless mobility management scheme. Some of the challenges include increased coordination and management complexity, signaling overhead, higher packet loss and handover delay due to frequent handovers. Software Defined Networking (SDN) has been proposed as a potential solution to address some of these challenges. In this work, we study the current 3GPP X2-based local mobility handling mechanism, and propose an SDN-based architecture that integrates the SDN paradigm into an X2-based local mobility management scheme in an enterprise femtocell network. We mathematically analyze the performance gain of the architecture by generating a closed form expression of the proposed scheme, minimizing both the signaling overhead and the handover latency.**

Keywords: 5G, RAN, Femtocells, HeNB, X2-interface, Mobility Management, SDN, SDN Controller

I. Introduction

In recent times we have witnessed a huge increase in the number of mobile devices, applications and services offered in mobile networks. According to [1], in 2015 more than half a billion mobile devices and connections were added causing a 74% mobile data traffic growth. Global mobile data traffic is expected to grow nearly eight folds between 2015 and 2020. The current generation of mobile networks has shown limitations in handling the foreseen number of mobile devices and traffic volume, mainly due to architectural ossification and spectrum access limitation, apart from scalability, flexibility and reliability issues. In line with this, some research activities have already begun to address the 3G/4G mobile network performance limitations, [2], [3]. It is believed that most of the new ideas in 5G will be based on the evolution of LTE/LTE-A.

The deployment of small cells (femtocells, picocells and microcells) has been identified as key technology to improve the overall capacity of the Radio Access Networks (RAN). Femtocells, also called Home eNBs (HeNBs), are low-cost, low-power and short-range wireless access points and are usually used in indoor network scenarios. They can boost spectral efficiency by allowing signal transmission at close proximity and high frequency bands, and reduce coverage holes with higher frequency reuse factor. However, the massive deployment of femtocells might bring new challenges with respect to resource coordination, mobility handling and overall service efficiency. This is due to the fact that fast moving users can trigger many handovers and increase signaling overhead and packet loss, creating also a bottleneck in backhaul networks. To address these issues, the SDN approach is proposed as a natural candidate to design an architecture that provides an optimized and efficient mobility management scheme [4].

In our previous work [5] we discussed SDN-based local handover management approach, and our preliminary results have shown some performance improvement of the approach. In this paper, we extend the work in [5] by considering the impact of several factors, such as user velocity, cell residence time and average session packet arrival rate, on the overall handover handling cost. The contribution of this paper is summarized as follow:

- We propose a centralized SDN-based local mobility management scheme for enterprise femtocell networks.
- We analytically model a cluster of femtocells to study user mobility behaviour, provide a centralized handover signaling procedure and drive closed form expressions for local handover handling.
- We present numerical results to highlight the performance gains of the proposed approach in terms of overall signaling cost.

The paper is organized as follows: section II presents background on SDN and X2-based local mobility management scheme, in section III we discuss the proposed architecture. Section IV describes user mobility model and mathematical formulation of handover signaling procedure, in section V we present analytical results and discuss the performance gains of the proposed approach. In section VI we conclude the paper by proposing future activities.

II. Background

A. Software Defined Networking

SDN is a new networking paradigm where the key concept is the decoupling of control and data planes, and the centralization of the control plane. It introduces flexibility and programmability into network and devices, enabling network operators to easily integrate new service requirements, while simplifying management and operational costs. In SDN, network devices act as a simple forwarding hardware, which takes the forwarding decisions based on data flows that are identified and categorized by several packet header fields. A centralized SDN controller uses a southbound Application Program Interface (API) to communicate with forwarding devices. OpenFlow is considered as the most common protocol. On the other hand, the SDN controller uses a northbound API to communicate with the application layer that enables network administrators to decide on how to handle forwarding plane, remotely shape traffic and deploy service policies [6]. Even though it is still in its infancy, SDN use cases continue to emerge with different roles in different networks and applications. Some practical implementation have also emerged by companies, such as Google [7].

B. Software Defined Mobility Management

Some existing works on the integration of the SDN paradigm into mobility management aim to address current general mobility management issues in wireless and mobile networks. The authors in [8] [9] raise some challenges in IP mobility management schemes, such as triangular routing and handover inefficiency. They proposed a centralized approach with extension of OpenFlow interface for inter-domain mobility management. The work in [10] proposes an SDN based traffic forwarding approach for small cell backhaul LTE networks with a centralized controller for the control plane within a radio access network and the data plane in the core network. The work in [11] investigates an SDN approach for IETF's Distributed Mobility Management (DMM) scheme to address sub-optimal routing and inter-domain tunneling issues. The authors in [12] try to address layer 2 traffic pause time in SDN-based enterprise networks by proposing a handover preparation scheme that employs a location server and central SDN controller with mobility applications. The work in [13] shows the benefits of deploying a local mobility anchor for centralized mobility handling and local data forwarding with X2-interface in femtocell networks. [14] and [15] discuss the evolution of mobility management in mobile networks, and suggest several possible SDN-based approaches for minimizing handover signaling overhead in future 5G networks.

C. 3GPP X2-based local mobility management

Mobility management is maintaining mobile users connectivity to the network while changing the point of attachment. It constitutes location and handover management tasks to maintain the reachability of a mobile user. Handover management involves handover preparation, handover execution and handover completion functions to perform tasks like handover triggering, routing user packets, identifying ongoing session and releasing resources [16]. A main challenge of mobility management schemes is to minimize the handover latency for maintaining a high level of quality of service [17]. In what follows, we discuss the X2-based local mobility management protocol commonly used in current generation mobile networks.

The X2-interface has been supported in 3GPP since release 10 and has been defined in recent release 14 [18]. LTE/LTE-A supports X2-based local mobility management scheme between HeNBs or eNBs. The X2 protocol stack enables HeNBs to establish a direct connection in order to exchange control information and forward data for a network-controlled UE-assisted handover. Fig.1 shows the standard X2-based handover procedure performed without Evolved Core Network (EPC) involvement, i.e. handover signaling messages are directly exchanged between the HeNBs, where neither Mobility Management Entity (MME) nor Serving Gateway (SGW) changes [18], [19], i.e., mobility handling within a subnet. The procedure is summarized as follows.

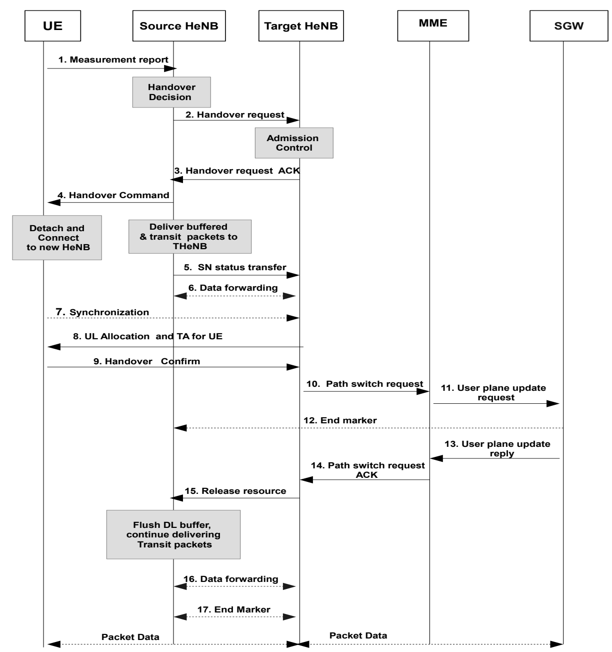

Fig. 1. 3GPP X2-based local mobility management signaling [18]

- UE sends a periodic *measurement report* to source HeNB (SHeNB) for *handover decision*, based on this SHeNB triggers and sends *handover request* to target HeNB (THeNB) over X2-interface.
- The THeNB performs an *admission control* and responds with a *handover request Ack*, and SHeNB sends *handover command* towards UE.
- UE detaches from the associated SHeNB and *synchronizes* to new THeNB, meanwhile SHeNB *buffers and delivers* UE packets to THeNB using X2-interface.
- Up on *syncronization* with UE, the THeNB sends an uplink resource allocation information for UE in order to confirm the handover procedure.
- THeNB sends a *path switch request* to MME, the MME sends a *User Plane Update Request* to the SGW about to which HeNB the packets for UE shall route.
- Finally, after receiving *Path switch request ACK* and *End Marker* from SGW, THeNB sends *Resource Release* to SHeNB to release resources. This completes the local handover process.

III. Proposed SDN-based Local Mobility Management with X2-interface

A. Motivation

Mobility Management is a key research item in 5G mobile networks, since femtocells are expected to be massively deployed in various indoor and outdoor network scenarios such as airports, stadiums and malls. According to 3GPP [18] femtocells may support fixed broadband access network interworking function to signal tunnel information to core network entities, such as forwarding path information. With X2-based handover support, mobility management signaling load in femtocell networks can be reduced at least by a factor of six, as compared to the traditional S1 signaling, [20], [21]. On the other hand, SDN has the ability to move most of the network intelligence to a logically centralized controller, providing a real-time adaptation to changing network conditions. Therefore, we believe that future generation of networks will consider an evolutionary approach for mobility handling. A centralized SDN-based handover management approach with direct X2-interface has the potential to implement a fast, network aware and optimized local mobility scheme.

B. A centralized SDN-based architecture

Fig. 2 shows a typical enterprise femtocell network scenario, where we consider a local mobility management approach based on a centralized SDN controller with direct X2-interface between femtocells[1]. In this scenario, the SDN controller decouples the control plane from the data plane, handles the necessary handover signaling and manages the mobility of users within the enterprise network. Furthermore, it provides a common control protocol such as OpenFlow that manages multiple compatible HeNBs with a primary task of data forwarding. We assume the central controller includes the MME/SGW functionalities, and it gathers network status information and exchanges handover related messages with HeNBs and UEs in the network. Moreover, the enterprise HeNBs can be either an existing HeNB with an OpenFlow switch on top of it or a new future HeNB with integrated open standard protocol stack (OF-HeNB), as represented in Fig. 2.

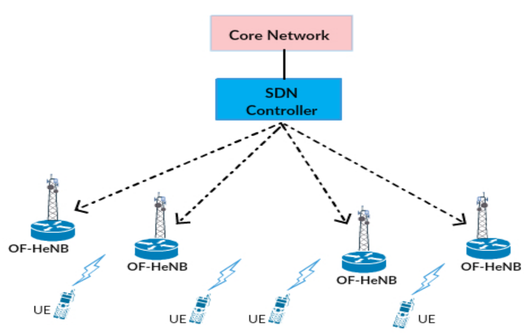

Fig. 2. SDN-based local mobility management in femtocell networks

The main benefit of this approach lies on the centralization of handover decision, admission control and forwarding path computation in the SDN controller. Fig. 3 depicts a simplified handover signaling sequence for a user moving within a femtocell network with SDN controller replacing MME/SGW. It shows how the proposed approach can reduce the number of handover message exchanges as compared to 3GPP standard scheme in Fig. 1. We assume a UE-assisted network-controlled handover management approach where a periodic *measurement report* is sent to the SDN controller through the HeNBs, shown as message *00* in Fig. 3, which can be used for network-load based handover decision by the controller. In addition, the *Handover Command* constitutes radio resource configuration details for the UE before switching its point of connection to THeNB. We summarize the main features of this approach as follows:

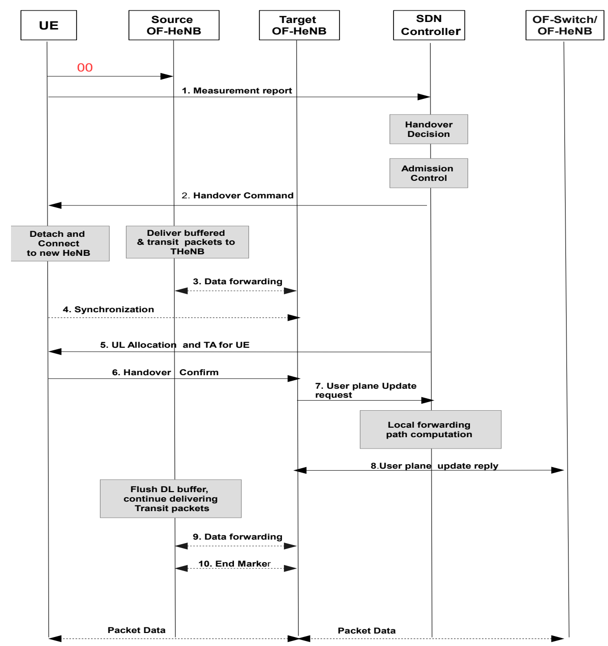

Fig. 3. Proposed SDN-based local mobility management signaling

- ***Handover decision***: this function is centralized in the SDN controller, while 3GPP standard employs a distributed handover decision function in SHeNB. The SDN controller facilitates a resource efficient handover decision, where decisions can be taken based on overall network information such as user location, network load and mobility pattern. Note that location management and handover decision details are not considered in this work.
- ***Admission Control***: a centralized admission control and resource management is proposed, which enables a resource-flexible, network-aware and secure decision making by the central controller. In the standard 3GPP approach this function is taken care by the THeNB with distributed resource control approach.
- ***Data forwarding orchestration***: the SDN controller orchestrates the local X2-based data forwarding among HeNBs during and after handover completion. The controller with overall network overview can setup an optimum forwarding path proactively by exchanging Open-

[1] Femtocells are shown as OF-HeNBs in Fig. 2

Flow messages with HeNBs. This will reduce the signaling required to setup a path with S1 signaling procedure during handover in the 3GPP standard mobility handling procedure. Moreover, the SDN controller will also be able to take a better decision for the target HeNB, if it knows the load of the HeNB and how the load changes over time.

- ***Cost and energy efficiency***: In this approach, the handover process requires less involvement of UEs and HeNBs than the standard 3GPP. Due to the integration of HeNBs handover and MME control functions in the SDN controller we can reduce handover messages between SHeNB an THeNB. That means, we can achieve a cost and energy efficient handover scheme.

Comparing Fig. 1 and Fig. 3, with SDN-based approach we can reduce the total number of handover signaling. Messages number *2*,*3* and *5*, as seen in Fig.1, can be reduced because of handover and admission control functions centralization. In addition, messages number *10*,*12*,*14* and *15*, as seen in Fig. 1, can also be minimized as a result of a centralized network overview in the controller. However, there is a need to send OpenFlow commands, messages number *7* and *8* shown in Fig.3, from the controller to the OpenFlow-enable HeNBs in order to update forwarding path, which can be done through the fixed access connection without having to compete for the wireless resources.

IV. Model Description and Mathematical Formulation

A. User mobility Model

We use the fluid-flow mobility model to represent user mobility behaviour in our network scenario Fig. 2, [22] [23]. This model is primarily used in determining the boundary crossing rate and residence time within a given radio range in the context of movements of nodes in mobile and cellular networks. In this model, we assume that the mobile users are uniformly distributed over a [0,2π) circular femtocell of coverage area (A) and is likely to move in any direction with equal probability with an average speed of v. Accordingly, the average cell border crossing rate u_c of mobile user per unit time is given by (1) [22]

$$u_c = \frac{vL}{\pi A} = \frac{dvL}{\pi} \tag{1}$$

Where L is the perimeter of a cell, and d is the user density. Consequently, the mean cell residence time is given by

$$E[t_c] = \frac{1}{u_c} \tag{2}$$

Let p_h be the probability of handover within the femtocell network, i.e, the probability of moving out of a particular cell and is given by equation (3)

$$p_h = 1 - \frac{1}{N} \tag{3}$$

Where N is the total number of HeNBs in the network. In [24] it is shown that the rate of mobile users moving out of a cell is equal to the mean cell residence time times the average number of active users in the cell $E[N_c]$. Furthermore, assuming homogeneous cells, the average rate of inter-cell handover is equal to the rate of the mobile users moving out.

Let $E[N_c]$ be the average number of HeNB crossing and $E[N_t]$ be the total number of HeNB crossing within the SDN controlled domain, we can define

$$E[N_c] = \frac{u_c}{\lambda_s} \tag{4}$$

$$E[N_t] = p_h \times E[N_c] = p_h \times \frac{u_c}{\lambda_s} \tag{5}$$

λ_s is a Poisson session arrival process, while the u_c and t_c follow an exponential distribution model[2]. Equation (5) indicates the total number of handovers within the network.

B. Total signaling cost analysis per user

For performance evaluation of the proposed approach, we define a total handover signaling cost S_c as a sum of a signaling cost C_{signal} and packet delivery cost $C_{delivery}$ per user as

$$S_c = C_{signal} + C_{delivery} \tag{6}$$

The C_{signal} is calculated as transmission and processing latency, while $C_{delivery}$ is packet delivery overhead cost, both based on 3GPP standard values [25].

1) 3GPP-X2 total cost analysis: To analyze the 3GPP total cost, we use Fig.1 as a benchmark, let T_{X2} and T_{S1} be the transmission latency over X2 and S1 interfaces, respectively, and P_{HeNB} and $P_{MME\text{-}SGW}$ be the processing latency at the HeNBs and MME/SGW respectively. Then the total signaling cost is given as

$$C^{3GPP}_{signal} = E[N_t]\big(9T_{X2} + 5T_{S1} + 7P_{HeNB} + 2P_{MME\text{-}SGW}\big) \tag{7}$$

equation (7) accounts T_{X2} for messages 1-5,7,9,15 and, 17, and T_{S1} for messages 10-14 in Fig. 1. While P_{HeNB} and $P_{\mathrm{MME\text{-}SGW}}$ are processing latency at the SHeNB/THeNB and MME/SGW respectively. Let r_{p} be the average packet transmitted and received by a single user per session, i.e., time interval between the first packet of a data session and first packet of the next data session, then delivery cost is

$$C^{3GPP}_{delivery} = r_{\mathrm{p}}\Bigg(T_{S1} + E[N_t]\big(lookup_c + tunneling_c\big)\Bigg) \tag{8}$$

where $lookup_c$ is the lookup cost at HeNB during preparation to send towards a destination HeNB, and $tunneling_c$ is the tunneling cost to forward packets towards THeNB.

2) SDN-X2 total cost analysis: To analyse the total cost with SDN-based approach, using Fig. 3 as reference we have.

$$C^{SDN}_{signal} = E[N_t]\big(6T_{X2} + 2T_{OF\text{-}Switch} + 4P_{HeNB} + 3P_{SDNC}\big) \tag{9}$$

where P_{SDNC} is processing latency at the SDN controller and T_{X2} accounts for messages 1,2,4-6 and 10. The SDN controller has to update all the nodes that are involved in a path setup operation by sending an OpenFlow command, thus $T_{OF\text{-}Switch}$ is the transmission latency between OpenFlow-enabled HeNBs

[2]Poisson process and exponential distribution models are commonly used to represent the arrival process and residence time of mobile user in mobile networks.

and SDN controller which accounts for messages 7 and 8 in Fig. 3. We assume that the delay for updating HeNBs for path setup should be larger than it is required for other message such as the *measurement report*.

$$C^{SDN}_{delivery} = r_{\mathrm{p}}\Bigg(E[N_t]\big(lookup_c + tunneling_c\big)\Bigg) \tag{10}$$

As can be seen in the equation (10) we have not included the term T_{S1}, because with a centralized controller we can localize the path switch computation and avoid the need to signal the SGW for a new path setup, as seen in Fig. 3.

V. Results and Discussions

In this section, we compare the total handover signaling cost for 3GPP standard and the proposed scheme, applying the closed-form expressions in equation (5) - (10) and standard 3GPP parameters [25] shown in Table I. Since we assume that the SDN-controller acts as a MME/SGW, the respective values of $T_{OF\text{-}Switch}$ and P_{SDNC} are same as T_{S1} and $P_{MME\text{-}SGW}$, it might even be less than the given standard values for enterprise networks but we compare performance gain for worst case scenario.

TABLE I
Performance analysis parameters

Parameter	Value	Parameter	Value
T_{X2}	15ms	$lookup_c$	1ms
T_{S1},$T_{OF\text{-}Switch}$	50ms	$tunneling_c$	1ms
P_{HeNB}	4ms	r_{p}	50
$P_{MME\text{-}SGW}$, P_{SDNC}	15ms	λ_s	$1/s$
L	200m	No of HeNBs	5 - 50
User density	5 - 50	UE speed	0 - 30Kmph

According to small cells forum [26] the enterprise use case is described as generally indoor, premises-based deployment beyond home office with large geographical area and high number of users. Thus in this section we analyze the effect of user density, user velocity, and analyze scalability by increasing number of HeNBs and average session packet arrival rate.

Fig. 4 shows the impact of the mobile user speed v on the total handover signaling cost. We can observe that with SDN-based approach we can achieve a reduced signaling cost, by more than 50% as compared to the standard 3GPP scheme, particularly for users moving with high speed. This is due to the handover function centralized in the controller which results in a reduced signal exchange between HeNBs for fast and seamless mobility handling. As seen in equation (1), the cell border crossing rate is directly related to the speed of the users in a cell.

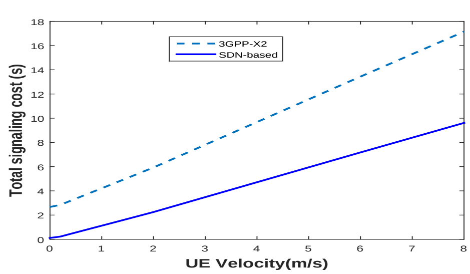

Fig. 4. Impact of user velocity on total signaling cost

Fig. 5 shows the impact of user density (per m^2) on the signaling cost, the user density in a femtocell network affect the cell crossing rate in direct proportion as shown in equation (1). We observe that the signaling cost increases as the number of users increase in the femtocell area. In addition, for highly dense femtocell networks the cost is much higher in case of 3GPP X2 scheme than for the proposed SDN-based scheme. Thus, the proposed handover scheme will enable a low signaling mobility mechanism for future highly populated HetNets.

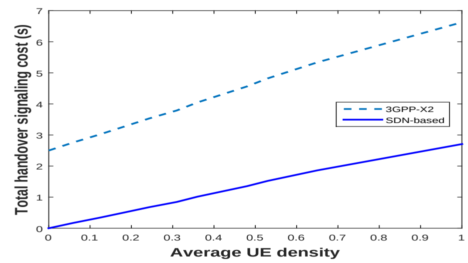

Fig. 5. Impact of user density on total signaling cost

In Fig. 6 we present the impact of network size, by increasing the number of HeNBs deployed in the network for different cell border crossing rate. the relative signaling cost represents the relative difference in total signaling cost of the 3GPP and SDN-based schemes. As we can see in Fig. 6, with increasing HeNBs and mobility rate the SDN-based handover management achieves a relatively reduced signaling cost as compared with the standard X2 scheme. This indicates that with a centralized approach we can achieve a more scalable femtocell deployment as it generates less signaling cost with increasing HeNBs and speed. This implies that the SDN-based scheme could be a feasible approach to achieve an optimized and scalable mobility management solution in future dense deployment of femtocells.

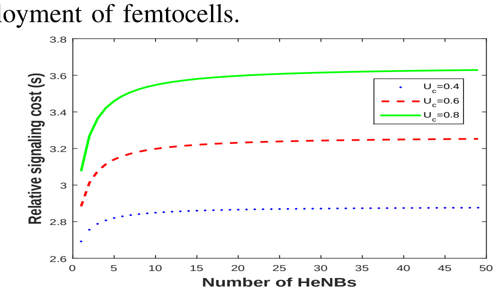

Fig. 6. Impact of network size on total signaling cost for different user speed

To study the impact of ongoing traffic on the generated signaling cost, we vary the average number of packet arrivals r_{p} per session. As shown in Fig. 7 the total signaling cost of centralized approach is significantly reduced in comparison to the standard 3GPP scheme. This happens mainly due to the use of X2 local forwarding scheme and the reduction of path switch signaling exchange between THeNB and SGW. With the central SDN controller, HeNBs will be able to broke traffic locally without requesting a new path for each cell change, while in the standard scheme each handover case has to make a path switch operation between THeNB and SGW.

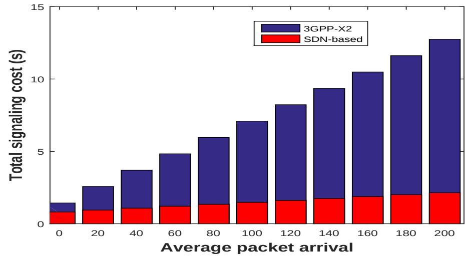

Fig. 7. Impact of Average packet arrival per session on total signaling cost

Apart from the performance gains of SDN-based scheme, the proposed approach might also have some drawbacks. The SDN controller processing capacity limitation and the fact that it can be a single point of failure can be considered as challenges of the proposed solution. In addition, enterprise femtocell networks require a high quality fixed access networks for low delay communication with all data plane nodes. Furthermore, the direct X2-interface works only between neighbouring HeNBs which can also be seen as a bottleneck for forwarding path optimization by the SDN controller.

VI. Conclusion and Future Work

Femtocells offer wide opportunities for achieving a high data transmission and extended coverage in future mobile and wireless networks. On the other and, SDN promises a flexible and network-aware implementation of services and applications to meet future network demands. In this paper, a centralized SDN-based local mobility management approach with X2 forwarding scheme is proposed to show how the SDN paradigm can be integrated into mobile networks. We have shown that this approach can reduce total handover signaling cost by minimizing the number of signaling exchanges between nodes and by allowing a local forwarding path computation in a centralized manner. In the future, we plan to further extend the SDN-based approach to include all types of small cells, since any or all of small cells can be based on femtocell technology, i.e. the collection of standards, open interfaces etc. Moreover, we plan to investigate location management, inter-domain mobility, and the suitability of the approach in heterogeneous networks with multi-radio technology.

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