Fast Handover in Cellular Networks with Femtocells

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***Abstract*—With the advent of femtocells in cellular networks, the inter-cell handover process will become more complex, frequent and time-sensitive. The legacy handover procedures in 3G and LTE systems were originally designed for handovers between macrocells whose base stations are part of the mobile core networks. The use of the public internet to connect the femtocell base station with the mobile core network will contribute to higher latency if such legacy handover procedures are employed over femtocells. This makes the legacy handover procedures slower, and in most cases inefficient. In the absence of a specific standardized procedure that involves femtocells, rather than using existing procedures designed to handle handovers between macrocells, we propose a new Prefetch-based Fast Handover procedure that is designed to overcome the drawbacks introduced by the usage of the public internet for message paths between femtocell base stations and the mobile core network. The new procedure can be introduced into the existing LTE infrastructure with few modifications to the femtocell base station architecture, and the core network packet flows. The proposed procedure simplifies and speeds the handover procedure at the cost of consuming more network resources at the femtocell base station.**

I. Introduction

Handover procedures are an integral part of cellular network design, since the user nodes, also known as the User Equipment (UE), in these networks are inherently mobile. When a UE moves to a region where the strength of signal it receives from its associated macrocell base station, also known as NodeB or enhanced-NodeB ((e)NB), is significantly lower than that of a new (e)NB, a handover procedure is triggered. Simply expressed, when a UE moves closer to a new (e)NB than its currently associated (e)NB, it switches its association to the new (e)NB and this switching process is called a handover. A handover procedure aims to be fast enough to maintain its transparency to the running applications [1].

In traditional cellular networks, the standardized legacy handover processes are managed by the Mobile Core Network (MCN). The macrocell (e)NB, which the UE associates with is a part of this MCN. As a result, traditional handover procedures are designed with an assumption that the latency is minimal between the (e)NB and other entities of the MCN involved in the handover [2]. However, this assumption is now invalid with the introduction of femtocells in cellular networks.

A femtocell is a small cell with a Home-(enhanced) NodeB (H(e)NB) as its base station. The H(e)NB is a low power and low cost base station overlaid on the existing cellular network. Normally installed indoors, it is connected to the user's broadband service modem much like a WiFi access point. Femtocells provide a high-speed data connection to subscribers within a small range [3]. Thus, the fundamental difference between a femtocell and a macrocell is in their respective backhauls. A femtocell's backhaul is an interface to the MCN through the public internet, as opposed to the backhaul of a macrocell, which has dedicated lines to the MCN. While it typically takes less than 100 ms for a handover between macrocells [4], it could take well over 200 ms to transmit a single message over the public internet. Currently, there is no standardized procedure that specifically handles handovers involving femtocells. Thus, if the legacy handover procedure were to be applied to such handovers, the introduction of the public internet between the H(e)NB and the MCN will introduce additional latency. Moreover, because of the small size of femtocells, the frequency of handovers will also increase. As a result, a fast moving UE may find it hard to keep connected with fast passing femtocells in its path. In order to maintain higher layer services, it may thus either forgo handovers into femtocells and use the weaker, overburdened macrocell, or employ this procedure only for lower speed users (e.g., pedestrians). For mobile UEs to take maximum advantage of the fast passing femtocells thus further offloading macrocell traffic to femtocells, a faster handover procedure is required. A fast handover process must also be designed to better suit the new cellular network architecture that includes femtocells connecting to the MCN via the public internet.

While there is considerable focus in the research community on femtocell networks, the issue of handover has been less studied. More recently however, ideas such as proactively triggering handover procedures by predicting mobility of users [5], reducing the scanning time to identify associable femtocells by caching recently visited cell information [6], reducing unnecessary handovers by modifying the architecture and signal flow [7][8], have started appearing in the literature. There are also been some work focusing on increasing handover efficiency in other networks such as WMAN [9] and WiMAX [10].

In this paper, we propose a Prefetch-based Fast Handover procedure that requires little change to the existing MCN architecture. The procedure aims to prefetch higher layer data to nearby femtocells by decoupling the portions of the existing handover procedures that occur before and after the actual handoff of the UE. As a result, we can substantially reduce the time spent in signaling as well as data exchange between the femtocells and the MCN during the actual handoff, thus causing fewer and shorter interruptions to the higher layer sessions, and tapping the potential of a larger set of available

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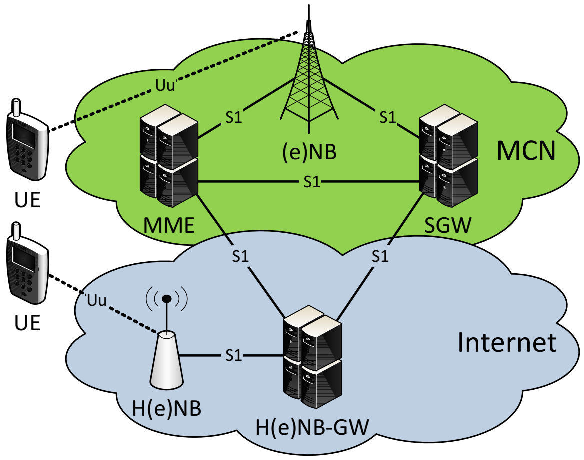

Fig. 1. Relevant Components of 3G/LTE Architecture

femtocells. By using more femtocells in the path of the mobile UE, we also reduce the load on the macrocell and hence increase the network capacity.

The rest of the paper is organized as follows. We begin in Section II by describing the existing 3G/LTE cellular network architecture and handover procedures. Section III then details the proposed fast handover procedure. Section IV presents the simulation system used for evaluation, followed by the results and analyses. We end with a discussion of possible enhancements and conclusions in Sections V and VI, respectively.

II. LTE Network Architecture and Handover

The 3G and LTE network architectures were designed with a focus on macrocells, femtocells being a relatively new addition to the existing components [11]. Figure 1 illustrates the relevant components of the LTE network architecture from the handover perspective. The Serving Gateway (SGW) supports user data and provides routing and forwarding functionality between (e)NBs (or H(e)NBs) and the Packet Data Network (PDN). It also acts as the mobility anchor during handovers between LTE and other 3GPP systems [12]. All base stations ((e)NBs and H(e)NBs) connect to the MCN and the Packet Data Network (PDN) through the SGW for control signaling. The Mobility Management Entity (MME) is the key control node for LTE access network. It provides the control plane function for mobility between LTE and other access networks, and is responsible for choosing the right SGW for a UE and for authenticating them.

A H(e)NB Gateway (H(e)NB-GW) is used to provide interface scalability and support to a large number of H(e)NBs [13]. It works as a concentrator for the control plane.

A. The LTE Handover Procedure

A UE periodically scans all available channels to measure signal strengths and reports the measurements to its associated (e)NB or H(e)NB in a *Measurement Report* message. A handover process is triggered by a positive *Handover Decision*, which happens every time a *Measurement Report* suggests that the best signal received by the UE is from an (e)NB or an H(e)NB that it is not associated with [14]. Figure 2 shows how the legacy handover procedure used in LTE networks is normally expected to be extended for a femto-femto handover. Control message exchanges are shown in blue, while data is shown in red. Bold dashed arrows indicate messages having to go through the public internet, and are hence slower. *Src H(e)NB* is the femtocell the UE is currently associated with and *Tgt H(e)NB* is the femtocell that the UE is to be handed-over to.

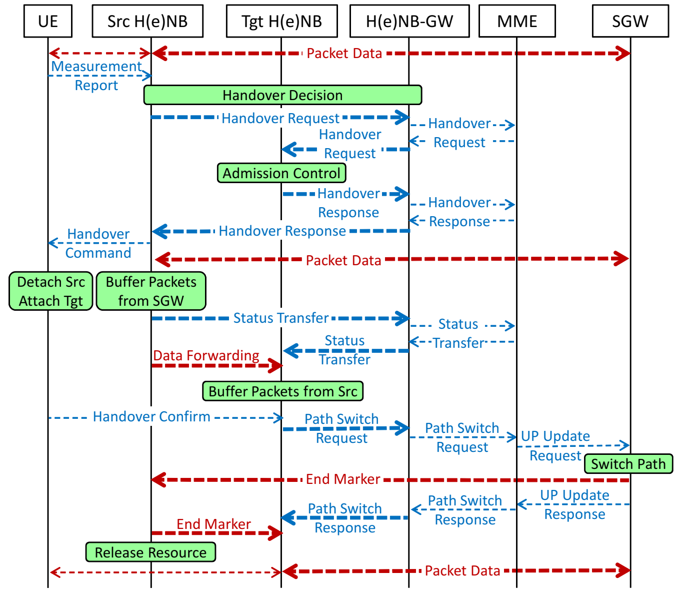

Fig. 2. Legacy Handover Procedure

- When a positive *Handover Decision* is made by the Src H(e)NB, it sends a *Handover Request* message to the Tgt H(e)NB via the MME.
- The Tgt H(e)NB then performs *Admission Control* for the UE, and responds with a positive *Handover Response* message.
- When the Src H(e)NB receives the *Handover Response*, it issues the *Handover Command* to the UE, which then detaches from the associated femtocell and tries to handoff to the new femtocell.
- In the meantime, the Src H(e)NB starts to buffer the application layer data it continues to receive from the SGW. It also sends out a *Status Transfer* message to the Tgt H(e)NB via the MME and then begins forwarding the data to it.
- The Tgt H(e)NB, after receiving the *Status Transfer* message, begins to buffer the data being forwarded by the Src H(e)NB and accepts the *Handover Confirm* message from the UE, thus allowing it to associate with itself.
- The Tgt H(e)NB then begins transmitting the buffered data to the UE. The data at this time, goes from the SGW to the Tgt H(e)NB via the Src H(e)NB, traversing the public internet twice.
- Finally, the Tgt H(e)NB issues a *Path Switch Request* to the SGW, which then switches the data path and responds with a *Path Switch Response* message.

- The SGW then sends an *End Marker* data packet to the Src H(e)NB and then switches the data path so that it now streams the data directly to the Tgt H(e)NB. The Src H(e)NB forwards the *End Marker* packet when it is done forwarding all the data it has been receiving and buffering from the SGW.
- The Tgt H(e)NB, after receiving the *End Marker* packet, begins to transmit data from the SGW directly to the UE. This marks the end of the legacy handover process.

B. Shortcomings of Legacy Handover

While this handover procedure is highly optimized for a cellular network consisting solely of macrocells [2], it has a few shortcomings when it involves femtocells. Although the UE is capable of receiving data during the time between when the *Handover Decision* is made to when the *Handover Command* is received, the data rate it experiences at this time is very low due to the weak signal from the Src H(e)NB. Secondly, the UE is unable to receive downlink data from the time it received the *Handover Command* until forwarded data from the Src H(e)NB arrives at the Tgt H(e)NB. Finally, even when the UE actually begins to receive the data, for a while this data is routed via the Src H(e)NB, which involved two traversals over the public internet. These shortcomings make the legacy handover applied to femtocells slow, inefficient and wasteful.

III. Prefetch-based Fast Handover

In order to overcome the shortcomings of the Legacy Handover procedure due to the introduction of femtocells in the network, we propose a Prefetch-based Fast Handover procedure. This procedure primarily involves modification of two aspects of the Legacy Handover procedure. First, the speed of the UE is factored into the *Handover Decision* function; and second, parts of the Legacy Handover procedure are segregated to prefetch higher layer data to all H(e)NBs in the proximity of the UE. These two aspects of Prefetch-based Fast Handover are described blow.

A. UE Modes in Fast Handover

In the Legacy Handover procedure, the *Handover Decision* is completely independent of the speed of the mobile UE. This is because when a UE moves into a new cell, handover is imminent and the UE has no other option. However, when a UE moves through femtocells, there is always a choice of whether it should handover to the femtocell or stay associated with the umbrella macrocell. When a user is moving too fast, it may spend very little time in a femtocell range. Thus, we categorize a UE to be in *Swift Mode*, when its estimated speed is higher than a pre-defined threshold θ, and in *Free Mode* otherwise. The *Handover Decision* function allows a UE to handover to a femtocell only when it it is in Free Mode. The approximate speed of the UE can be estimated from the measurement reports sent by it. When the UE is in Swift Mode, it is only allowed to handover to a macrocell, since it is moving too fast to sustain frequent handovers through femtocells. The value of the threshold θ is calculated based on the average handover speed of the network, the size of the femtocells and the expected utility of the time spent by the UE in the cell. If value of θ is set too high, it could cause loss of network capacity due to higher number of failed handovers. At the same time, if the value of θ is set too low, potential associable femtocells could be missed, again causing loss of network capacity.

B. Fast Handover Procedure

The Admission Control process (taking place before the actual handoff) and the Path Switching process (taking place after the actual handoff) in the Legacy Handover procedure are tightly coupled with the actual handoff. While this is appropriate for a closed, appropriately designed MCN involving comparatively rare handover events, it may need some modification when the MCN has branches spreading out over the internet (H(e)NBs) and when handovers become more frequent. In Prefetch-based Fast Handover, we aim to decouple the actual handoff process from the processes taking place before and after it.

We define the *associable region* of a femtocell as the region where the signal from its H(e)NB is stronger than that from the umbrella (e)NB and the neighboring H(e)NBs. (Other criteria such as a utility function or a function that takes into account interference management, may also be used). We then define the *proximity region* of a femtocell to consist of its associable region and its surrounding region, where the strength of the signal from its H(e)NB is within δ of the strongest of the signals from the umbrella (e)NB and the neighboring H(e)NBs. Thus, while a UE can be in the proximity region of many femtocells at the same time, it can only be in the associable region of one of them. The value of δ depends on the average handover speed of the network, and the speeds of the UEs involved.

In Prefetch-based Fast Handover, when a UE is in the proximity region of one or more H(e)NBs, copies of higher layer data is streamed from the SGW to each of those H(e)NBs. While only the associated H(e)NB transmits the data to the UE, the others buffer this data. Each of the H(e)NBs in proximity of the UE are ready for the UE to be associated with them in the near future and stand prepared for a handover. The actual handoff however, only takes place when the UE moves into the associable region of a femtocell, just as in Legacy Handover. Since we always ensure that a UE moves into the proximity region of a femtocell before moving into its associable region, we can prepare the H(e)NB for a potential handover and save precious time during the actual handoff. Thus, we segregate the handover procedure into the actual handoff process and two prefetch processes - Proximity Add and Proximity Release.

C. The Proximity Add/Release Processes

Figure 3 shows the Proximity Add and Release processes. The Proximity Add process takes place when a UE moves into

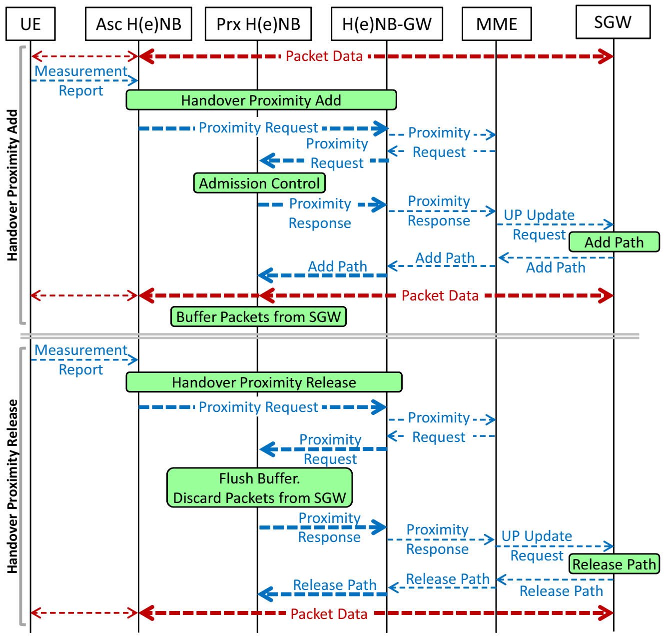

Fig. 3. Fast Handover Procedure: Prefetch Processes

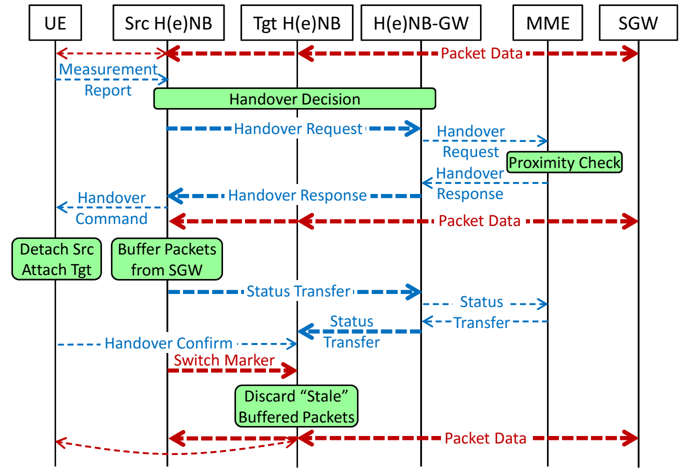

Fig. 4. Fast Handover Procedure: Handoff Process

the proximity region of a femtocell, and the Proximity Release process takes places when a UE moves out of it.

Based on the *Measurement Report* received from the UE, the associated H(e)NB (labeled as *Asc H(e)NB*) along with the H(e)NB-GW makes a decision whether to add the new H(e)NB (labeled as *Prx H(e)NB*) to the proximity of the UE. We call this as the *Handover Proximity Add* function.

- A positive *Handover Proximity Add* decision follows Admission Control in the Proximity Add process, which is similar to that in legacy handover with the only difference being that the associated H(e)NB does not need to be notified of its confirmation.
- The MME keeps track of the femtocells in proximity of the UE, and sends a user plane *Path Update Request* to the SGW to add a duplicate higher layer data stream to the new H(e)NB.
- The SGW sends the *Add Path* control message to the new H(e)NB with information about the new data stream to be initiated, and then creates a copy of the data stream already being sent to the Asc H(e)NB and starts streaming it to the Prx H(e)NB simultaneously.
- The new H(e)NB starts to buffer the received data to prepare for a possible near future association with the UE.

Similarly, the Proximity Release process is triggered when a UE moves out of the proximity region of a femtocell. Here the Prx H(e)NB flushes out the buffered data and the SGW stops streaming duplicate data to it.

D. The Fast Handoff Process

The Proximity Add and Release processes occur decoupled from the actual Fast Handoff process shown in Figure 4. This process is very quick because certain parts of the procedure are already taken care of in the Proximity Add process when the UE first entered the proximity region of the new H(e)NB (labeled as the *Tgt H(e)NB*), and some will be taken care of by the Proximity Release process when the UE leaves the proximity region of the currently associated H(e)NB (labeled as the *Src H(e)NB*).

- The *Handover Decision* function is exactly the same as that in the Legacy Handover procedure. This follows the *Handover Request* message sent from the Src H(e)NB to the MME which then performs the *Proximity Check* to ensure that the Tgt H(e)NB has already gone through the Proximity Add process for the UE.
- The MME then responds positively with a *Handover Response* to the Src H(e)NB which consequently sends the *Handover Command* to the UE, just like in the Legacy Handover procedure.
- The Tgt H(e)NB, which is already buffering higher layer data meant for the UE only needs a marker to know the point from which data needs to be transmitted to the UE. The Src H(e)NB sends the *Status Transfer* message to the Tgt H(e)NB followed by this *Switch Marker* packet.
- Upon receiving this, the Tgt H(e)NB discards those packets which have already been received by the UE (Stale Buffered Packets), and starts transmitting the data.

This marks the end of the Handoff process. The reader may note that while from the perspective of the UE, the process is exactly the same as the legacy procedure, the inner core network, including the SGW, is completely unaffected by it. There is no updating of data paths and no re-routing of data streams via any H(e)NB involved in the proposed process.

IV. Performance Evaluation

In order to evaluate the benefits of the Prefetch-based Fast Handover procedure, we simulate the system using the C programming language which allows more flexible implementation of procedure modifications, along with user mobility, compared to other simulation platforms. The implementation simulates a mobile UE driving at varying average speeds through streets in a specific residential neighborhood in Brooklyn, NY, shown in Figure 5, with varying number of the

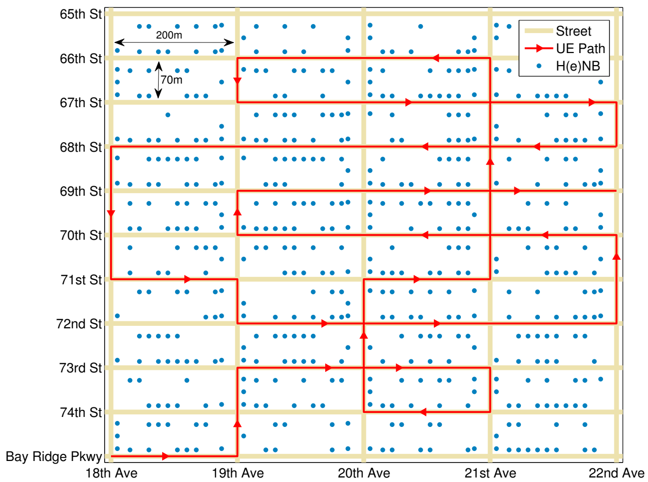

Fig. 5. Area Map showing path of the UE with 50% femto-residences

residences in the area having installed femtocells, shown as blue dots. Half of the residences in the neighborhood have femtocells installed in the setting shown in Figure 5.

A. Simulation Settings

1) Network Settings: In our simulation, the entire area under consideration is covered under one macrocell of radius 400 m with its (e)NB located at the center of the region. Selected residences have H(e)NBs installed, following a random uniform distribution, with a femtocell range of 50 m. Downlink transmission powers of all base stations are set such that the received SNR at the cell edge is 6 dB, as in [15]. Also, the setting of outdoor path loss and noise power parameters, and calculation of throughput statistics are the same as in [15].

2) Data Flow: We assume a higher layer session continuously running on the UE that demands infinite downlink data.

3) Transmission/Reception: The simulation runs in slotted time, with a time slot length of 2 ms. In every time slot, the downlink channel used by the UE is simultaneously reused by the macrocell and other randomly selected femtocells. Thus, the UE suffers from interference from the (e)NB as well as other surrounding H(e)NBs. In the associated cell however, the UE is given highest priority and receives data during its entire association period.

4) Mobility: The UE moves along a pre-defined specific path shown in Figure 5. At every turn, it randomly picks a speed, and moves at that speed until it arrives at the next turn. For the purposes of simulation all speeds of the UE are assumed to be below the speed threshold θ, so that the UE is always in Free Mode, thus enabling the UE to handover to femtocells whenever possible. For Prefetch-based Fast Handover, the proximity threshold, δ, is set to be 15 m from the periphery of a femtocell.

5) Handover Messaging: The UE, while associated, sends Measurement Reports every 100 ms. We assume the average message transmission time over the internet to be 200 ms, based on round trip time data collected from the internet. The functions involved in the handover procedures are assumed to consume 2 ms on an average.

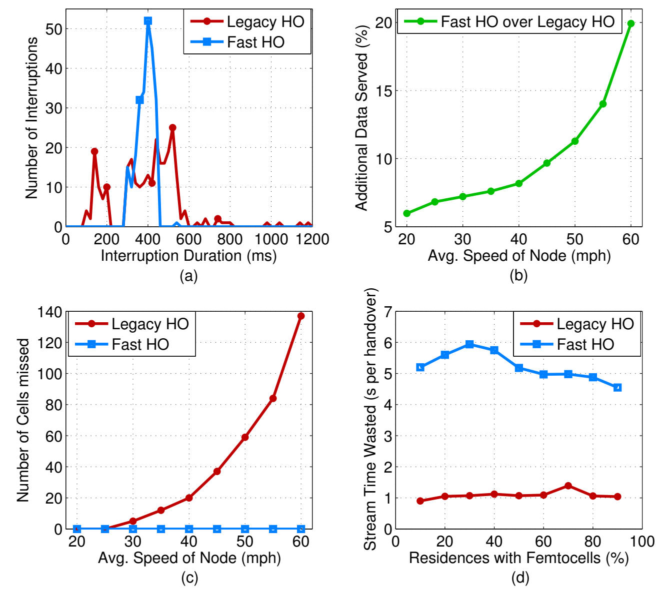

Fig. 6. (a): Interruption time distribution; (b): Additional data served by Prefetch-based Fast Handover over Legacy Handover with varying speed of UE; (c): Number of cells missed by the UE out of total 239 handover opportunities; (d): Unused data stream time with increasing femtocell density.

B. Results and Analysis

The average time taken for the full handover process across all simulation settings for Legacy Handover was 1.74 s, while it was found to be only 0.82 s for Prefetch-based Fast Handover. Thus, when compared with Legacy Handover, Prefetch-based Fast Handover procedure was found to take 53.1% less time on an average. Figure 6(a) compares the time during these handovers for which the UE was unable to receive any higher layer data packets. The average speed of the UE was set as 35 mph and 50% of residences had femtocells installed. While the average interruption in Prefetch-based Fast Handover was only 396.72 ms, it was found to be 509.7 ms in Legacy Handover. Besides the unavoidable interruption caused when the UE goes through the handoff, the Legacy Handover also causes interruptions due to interruptions in the flow of data forwarded from the Src H(e)NB to the Tgt H(e)NB, and interruptions due to the skipping of cells. These interruptions are reflected in the figure as interruptions smaller than 300 ms and larger than 560 ms respectively. Thus, while Prefetch-based Fast Handover only causes one interruption per handover, Legacy Handover cases many more. A large number of such interruptions result in large number of glitches in applications such as video calls.

Figure 6(b) compares the total amount of data served to the UE for the two handover procedures, with increasing UE speed. In this simulation setting, 50% of the residences have femtocells installed. Note that the data served to the UE is during its entire path, and not just when it goes through handovers. Although the UE spends a small portion of its time going through handovers, Prefetch-based Fast Handover is able to serve more than 7.5% additional data with an average UE speed of 35 mph, when half the residences have femtocells installed. The cumulative data served to the UE in Legacy

Handover, when it moves faster, drops drastically because it starts to skip handovers to femtocells on its path, as shown in Figure 6(c). In Prefetch-based Fast Handover however, the UE never skips a cell even at an average speed of 60 mph. As a result, when moving at an average speed of 60 mph, the UE can be served as much as 19.92% more data in Prefetch-based Fast Handover.

The benefits of Prefetch-based Fast Handover come at the cost of higher consumption of network resources, which occurs when prefetched data is discarded by a femtocell. Figure 6(d) shows a wastage of 4-6 s of streamed data per handover occurring across various simulation settings. The Legacy Handover procedure on the other hand only wastes about 1.09 s per handover on the average, while forwarding data from one H(e)NB to another.

C. Further Simulations

Motivated from the results produced above, we also simulated a similar network with 50% residences having femtocells, and 420 active UEs, of which a third are mobile. All UEs share the available downlink channels in a TDMA fashion, as in [15]. All UEs run a video streaming application that requires a minimum sustained data rate of 384 kbps [16]. We compared three systems - a) where mobile UEs are not allowed to handover to femtocells; b) where mobile UEs use Legacy Handover; and c) where mobile UEs use Prefetch-based Fast Handover. The system is said to be able to support a UE when it can be served at the required data rate for at least 90% of the time. We found the three systems to be able support an average 78.3, 102.6, and 129.4 UEs respectively. Thus, while allowing handovers to femtocells for fast moving UEs allows the network to support 31% more users, employing Prefetch-based Fast Handover enables the network to support 65% more users.

V. Discussion

The Prefetch-based Fast Handover is our first step towards increasing the efficiency of handovers in cellular networks with femtocells. There are various possible enhancements to the proposed procedure that can take it further in this direction. Implementation of a completely over-the-air or fast backhaul X2 link between H(e)NBs can make signaling between H(e)NBs faster and more efficient. Alternatively, implementation of a direct over-the-air control link between the H(e)NBs and (e)NBs can lead to transfer of all handover related signaling to this link. Since this can dramatically simplify and speed the handovers between femtocells, we will examine this case in future work. Finally, prediction of the user mobility based on available signal strength measurements and geographical data, can narrow down the number of femtocells in proximity of a UE, and hence reduce wastage of resources.

VI. Conclusion

In this paper, we presented Prefetch-based Fast Handover, a modified handover procedure that aims to tackle the shortcomings in Legacy Handover procedures introduced by an increasing number of femtocells in modern LTE cellular networks. We focus on fast moving UEs in the network that may otherwise fail to handover to quickly passing femtocells on their path. By enabling such UEs to handover to a larger number of femtocells, and by speeding the handover process, we allow fast moving UEs to take maximum advantage of femtocells in the network, rather than relying mainly on the macrocell. We make small modifications to the message flow in the Legacy Handover procedure, without making any changes to the system architecture, to achieve this faster and more efficient handover. This comes at the cost of a higher consumption of wireline network resources. Extensive simulations demonstrate reduction in handover time, reductions in the length and number of data interruptions caused by handovers, and better data service to the user when Prefetch-based Fast Handover procedure is deployed.

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