Reduction of Outage Probability due to Handover by Mitigating Inter-cell Interference in Long-Term Evolution Networks

Yaseein Soubhi Hussein, Borhanuddin Mohd Ali, Mohd Fadlee A. Rasid, and Aduwati Sali

The burgeoning growth of real-time applications, such as interactive video and VoIP, places a heavy demand for a high data rate and guarantee of QoS from a network. This is being addressed by fourth generation networks such as Long-Term Evolution (LTE). But, the mobility of user equipment that needs to be handed over to a new evolved node base-station (eNB) while maintaining connectivity with high data rates poses a significant challenge that needs to be addressed. Handover (HO) normally takes place at cell borders, which normally suffers high interference. This inter-cell interference (ICI) can affect HO procedures, as well as reduce throughput. In this paper, soft frequency reuse (SFR) and multiple preparations (MP), so-called SFRAMP, are proposed to provide a seamless and fast handover with high throughput by keeping the ICI low. Simulation results using LTE-Sim show that the outage probability and delay are reduced by 24.4% and 11.9%, respectively, over the hard handover method — quite a significant result.

Keywords: LTE, outage probability, multiple preparation, soft frequency reuse, radio resource control, inter-cell interference.

I. Introduction

A fast and seamless handover poses twin challenges for LTE networks to address, especially at high data rates. Hard handover (HHO), where a connection with a previous evolved node base-station (eNB) is severed before being handed over to the next eNB, is only to be considered in LTE networks using handover parameters, such as Layer 3 filtering (L-3), handover margin (HOM), and Time-to-Trigger (TTT) [1]–[2]. HHO suffers from some drawbacks, such as high outage probability, long delays, and unreliable break-before-make procedures [3]. In addition, it is difficult to maintain QoS requirements due to the delay incurred in the HHO during the eNB migration process, which is the process of moving from the serving eNB to the target eNB. Many studies have been conducted to improve HHO, and this issue has been reviewed well in [4]. There are others who have taken a different approach; that is, taking advantage of both soft handover (SHO) and HHO, as seen in [5]–[7]. In [5], the authors proposed a fractional SHO scheme based on carrier aggregation. In this scheme, it combines SHO and HHO depending on traffic. For example, for VoIP it performs an SHO, and for non-VoIP it performs an HHO, both of which are performed with a frequency reuse factor (FRF) of one. The authors in [6] and [7] used macroscopic diversity in an SHO. This resulted in a much better reduction of HO outage probability than that of [5], although none of them employed any type of ICI mitigation mechanism and where all studies used an FRF of one. A more numerical analysis has been presented in [7]. In [8], the authors proposed a bandwidth reservation based on a mobility

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prediction to guarantee an uninterrupted handover process. The reserved bandwidth is allocated to support the handover. This method can reduce outage probability but at the cost of wasting bandwidth, since it reserves a portion of the bandwidth from all six neighboring cells before a user is handed over; however, such a method is undesirable in LTE networks.

In this paper, we focus on the impact of inter-cell interference (ICI) on HO. LTE is specified as a frequency reuse-1 system to achieve maximum gain and efficient use of frequency resources. On the one hand, the optimal use of resources results in higher bit rates, but on the other hand, it induces ICI issues. In the absence of any interference mitigation or coordination mechanisms, ICI becomes critical in LTE HO. For example, interference will be high when neighboring eNBs assign the same resource block (for example, RB#4) to different UEs simultaneously. A number of schemes have been proposed to solve the problem of ICI. These schemes are categorized as either static or dynamic, according to their type of interference coordination mechanisms. Inter-cell interference coordination (ICIC) employs a static scheme that is known as fractional frequency reuse (FFR). Irrespective of the schemes, whether FFR or soft frequency reuse (SFR), most previous works have been done on the basis of the gains in cell border throughput, as described in references [9]–[15]. Another issue that can also benefit from ICIC is the HO mechanism [4], which is the focus of this work. In [16], an improvement of HO performance is based on the ICIC with an L-3 filter for optimization of HO parameters for HOM and TTT, where the main idea is taken from [17]. In ICIC, it is assumed that a target eNB always has resource blocks (RBs) available for incoming UEs. As this causes a loss of generality, it will not be considered in this paper. Our proposed scheme will be evaluated through an outage probability and will be compared against the benchmark work in [7], which is called a semi-soft HO.

The system model is described in section II. In section III, more details about the proposed scheme, performance metric, and reference signal received power (RSRP) are presented. The results and discussion are given in section IV. Finally, conclusions are drawn in section V.

II. System Model

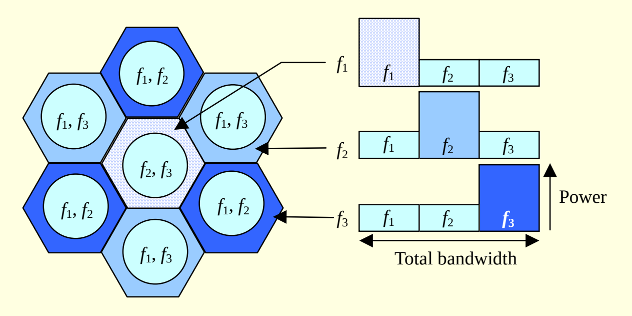

Fig. 1. SFR.

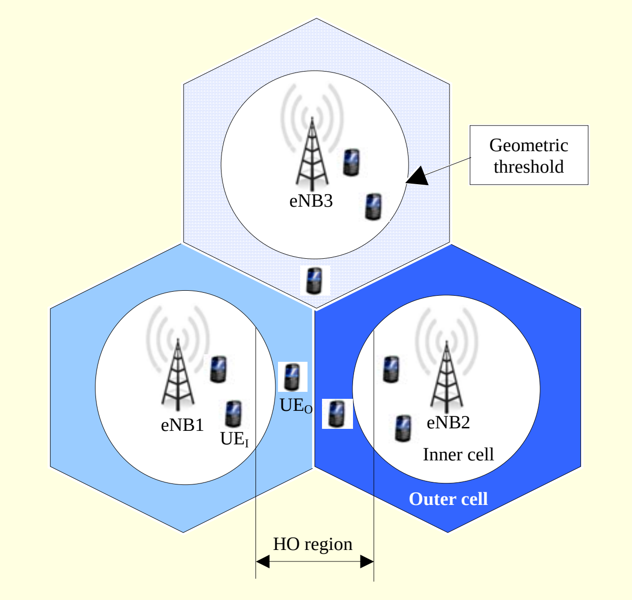

Fig. 2. Multi-cell scenario.

Figure 1 illustrates the SFR method that is implemented in the downlink (DL) of the eNB to mitigate ICI. The total bandwidth is subdivided into three sub-bands: f_1, f_2, and f_3. In the basic SFR, selecting an appropriate ratio for the inner part of a cell to the outer part of a cell is essential to mitigate ICI. We assumed that the ratio of the area of a cell center to the area of a cell edge is fixed at 1:3. Accordingly, the UEs could be separated into two groups: UEs belonging to the inner part of a cell (represented by UE_I) and UEs belonging to the outer part of a cell (represented by UE_O). This is done by measurement of the DL path loss. Henceforth, we call the inner part of a cell and the outer part of a cell as "inner cell" and "outer cell," respectively. The boundary between inner cell and outer cell is called the geometric threshold, as shown in Fig. 2.

The path-loss model used for a vehicular urban environment at 2 GHz can be expressed, as in [18], by

$$PL = 128.1 + 37.6 \times \mathrm{Log}_{10}(r)\,, \tag{1}$$

where r is the radius of a cell in km.

$$Geometric\_Threshold = PL|_{r=(r/3)}\,. \tag{2}$$

The mechanism for separating UEs is based on (2). If the path loss of a UE is greater than the geometric threshold, then the UE is considered to belong to group UE_O. Otherwise, the UE is considered to belong to group UE_I.

This is unlike FFR, where the bandwidth is divided into two sub-bands — the cell center and the cell edge. The cell edge in FFR is further subdivided into three sub-bands, where each sub-band faces different sub-bands of neighboring cells. This gives a lower ICI, not only for the cell edge but also for the cell center, since no subcarriers are shared. But, this consumes physical resource blocks (PRBs) or RBs. In LTE, radio resources are allocated in units known as PRBs, each of which contain twelve consecutive subcarriers for every slot of 0.5 ms duration in the time domain and 180 kHz in the frequency domain. A PRB is the smallest unit of bandwidth assigned to a UE by the eNB scheduler [19].

On the other hand, SFR mitigates the high ICI with a more efficient bandwidth utilization, since the entire bandwidth available can be utilised [20]. An eNB allocates high power for those subcarriers in the outer cells and low power for the inner cell subcarriers. The total transmit power of both the inner and outer cells should not exceed the eNB transmit power for the LTE, which is 43 dBm, just as in [15]. This type of power allocation arrangement in SFR improves the outer cell signal-to-interference-plus-noise ratio (SINR), while reducing the SINR for the UEs in the inner cell where low power is assigned.

In the proposed scheme, in addition to the SFR, the method of multiple preparations (MP) [21]–[22], which is a new feature of the LTE HO procedure, has also been implemented. In MP, the serving eNB can trigger the handover preparation toward multiple candidate eNBs. Even though only one of the candidates is indicated as the actual target, this approach speeds up recovery — so that in the case where a UE fails to connect to the target eNB, it can instead connect to one of the other prepared candidate eNBs. The source eNB receives only one “RELEASE_RESOURCE” message from the final selected eNB [21]. This will provide fair use of RBs among users and prevent wastage of radio resources. This proposed scheme is henceforth called Soft Frequency Reuse and Multiple Preparation (SFRAMP). Figure 2 shows a multi-cell scenario with the inner and outer cell areas.

MP in HO facilitates an improved handover procedure, which results in increased QoS and quality of user experience due to a reduction of outage probability. In Fig. 3, the messages exchanged during the handover preparation are described in the following steps:

1. According to the measurement report, a handover preparation is initiated by transmitting a handover request from the serving eNB to the indicated candidate handover targets, eNB1 and eNB2, requesting that a radio resource control (RRC) connection be set up.

2. An admission control is carried out on the target base stations, eNB1 and eNB2, indicating the successful reestablishment of an RRC connection. The handover is initiated by transmitting a handover request acknowledgement from the target base stations, eNB1 and eNB2, to the serving eNB.

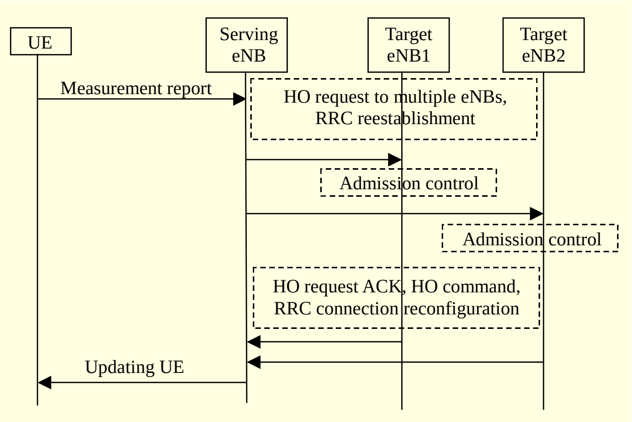

Fig. 3. MP process [22].

3. The handover request acknowledgement includes feedback information representing the admission control on the target eNBs and the RRC reconfiguration.

4. The UE is updated with the feedback information. RRC connection reestablishment is initiated when a UE in RRC_CONNECTED state loses its RRC connection, as specified in [2]. The total delay for RRC reestablishment can be expressed as

$$T_{\text{reestablish\_delay}} = T_{\text{UL\_grant}} + T_{\text{UE\_reestablish\_delay}} . \tag{3}$$

The UE reestablishment delay is

$$T_{\text{UE\_reestablish\_delay}} = 50\,\text{ms} + N_{\text{freq}} \times T_{\text{search}} + T_{\text{SI}} + T_{\text{PRACH}} , \tag{4}$$

where 50 ms represents the HO delay including 15 ms of RRC connection; N_{freq} is the total number of carrier frequencies available for RRC reestablishment; and T_{search} is the target cell search delay, where a target cell is not known when the HO command is received by the UE. For known target cells, $T_{\text{search}} = 0$, with signal quality being sufficient for successful cell detection. Otherwise, for unknown target cells, $T_{\text{search}} = 80$ ms. A target cell is considered to be known if the cell search requirements were met in the last 5 s; otherwise the cell is considered as unknown. The time required to read the target cell system information is represented by T_{SI}. The delay due to random access procedures is represented by T_{PRACH} [21], [23].

In SFRAMP the MP factor n is assumed to represent the carrier frequencies that are already prepared via MP. In other words, it can be defined as the unknown number of frequencies that are being known after MP is configured to multiple target cells. This configuration will increase the amount of known carrier frequencies, n, indicated to be detectable by the serving cell. Consequently, the target cell searching delay is minimized by

$$n \times T_{\text{search}} . \tag{5}$$

We can rewrite (4) as follows:

$$T_{\text{UE\_reestablish\_delay}} = 50\text{ ms} + \left(N_{\text{freq}} \times T_{\text{search}}\right) - \left(n \times T_{\text{search}}\right) + T_{\text{SI}} + T_{\text{PRACH}}. \tag{6}$$

This reduction of delay has been demonstrated in the simulation part as well.

III. System Analysis

1. Outage Probability

In a mobile radio environment there are several factors that influence quality of reception [24]. The first group are factors such as fast fading, path loss and shadowing due to the effects of objects on signal propagations, and physical distance. In addition, noise and interference can affect a UE's radio-reception quality. Hence, the outage probability, which is defined as the probability of an SINR being less than a specific threshold value [7], is used to evaluate the proposed HO scheme.

$$OP_{i,x} = P\left(SINR_i < SINR_{j,THR}\right), \tag{7}$$

where $OP_{i,x}$ is the outage probability of a UE at position x with serving eNB i and $SINR_{j,THR}$ is the SINR target threshold value for the neighboring eNB j. To reduce outage probability caused by high ICI, we apply the SFR in the DL. The SINR can be expressed as

$$SINR_i = \frac{P_{i,r}}{I_j + N}, \tag{8}$$

where $P_{i,r}$ is the UE's received signal power from the serving eNB and I_j and N are the interference and additive white Gaussian noise, respectively.

$$I = ICI + I_0, \tag{9}$$

where I_0 is the intra-cell interference, which can be neglected as it is obviated by the use of the orthogonal frequency-division multiple access (OFDMA) in the LTE DL. From (7)–(9) the outage probability becomes

$$OP_{i,x} = P\left(\frac{P_{i,x}}{ICI_j + N} < SINR_{j,THR}\right). \tag{10}$$

2. RSRP

In order for a UE to decide whether to do cell reselection or handover, various measurements have to be made. They are RSRP, reference signal received quality (RSRQ), and received signal strength indicator (RSSI). These measurements are also used by the eNB to decide whether or not to move the UE to other cells. In the case of a handover, the UE sends the measurement results according to the eNB commands (for example, at periodic intervals or if triggered by a certain event).

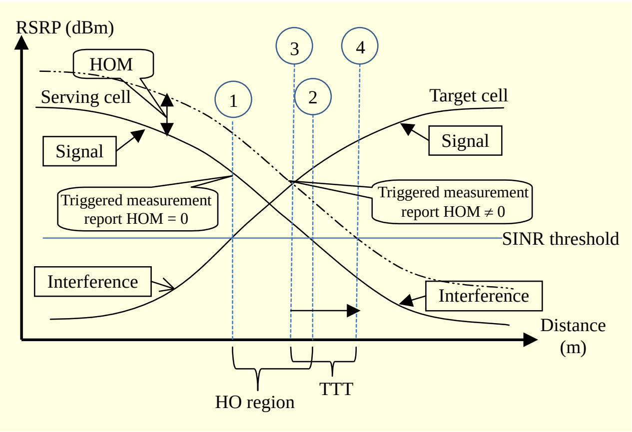

Fig. 4. UE measurements.

In Fig. 4, the section between points one and two (at which the UE starts sending measurement reports) is the HO region. The measurements and feedback that relate to the transmission settings are known as channel quality indicators (CQIs). Depending on the CQI value, the eNB takes the decision to assign a particular modulation and coding scheme (MCS) for a particular UE. The higher the CQI (ranging from 0 to 15), the higher the applied modulation and coding scheme; and the higher the achieved throughput [23], [25].

The signal quality for outer cells can be improved by using SFR, as explained in section II. We can rewrite (10) as follows:

$$OP_{i,x} = P\left(\left(\frac{E_s}{I_{ot}}\right)_{i,x} < SINR_{j,THR}\right), \tag{11}$$

where E_s/I_{ot} is the signal quality, which is defined as the energy per resource element (RE) of the synchronization signals divided by the total received energy comprising of noise and interference on the same RE. The number of UEs that can maintain condition (11) and prevent outage will therefore increase.

In LTE (Rel. 8), RSRP provides information about signal strength and RSSI helps in determining the interference and noise information [23]. Therefore, the RSRQ measurement and calculation are based on both the RSRP and RSSI [26].

$$RSRQ = N_{rb}\left(\frac{RSRP}{RSSI}\right), \tag{12}$$

where N_{rb} is the number of RBs in the bandwidth. The path loss can be expressed in terms of RSRP as follows:

$$PL = RS - RSRP, \tag{13}$$

where RS is the reference signal power broadcasted in system information block 2 (SIB) — a block that carries radio resource configuration information common to all UEs. The UE has to read the SIB2 to know the actual power at which the eNB transmits the RS [27]. Then the UE needs to compare the power difference between the RSRP and the RS in SIB2. Based on that, the UE can then compute the path loss using (13) [25]. A correct HO decision increases the capacity of the system, gives better coverage, gains higher throughput, and reduces latency [28]. On the other hand, an HO that is too late or too early will adversely affect the performance of the network.

3. HOM and TTT

The values of HOM and TTT have been specified by 3GPP [29]. HOM is a predefined parameter used to control the entering or leaving of the initiation of a triggered measurement report stage; this is triggered when the signal strength of a neighboring eNB is better than that of the serving eNB. The HOM various from 0 to 10 dB. This triggered measurement report is indicated in Fig. 4 at points one and two (namely, the HO region), where it can be seen that HOM equals zero. This HO region can be shifted to be between points three and two, where HOM is greater than zero. More optimization can be achieved using TTT. HO is executed when the HO condition in (16) is met during the TTT time period. The TTT time period is from points three to four. Shifting the HO region to three and four (with the assistance of the HOM) allows the UE to receive a higher level of RSRP; thus, depending on the CQI values, this may result in a higher MCS (as explained in section 2). If this is indeed the case, then it will improve user experience.

Meanwhile, TTT is the duration in which HO criterion is valid prior to HO execution. Once TTT is expired, the HO is executed and TTT varies from 0 to 5.120 seconds [29]. In this paper, the HOM and TTT are used as the HO parameters. Equations (14) and (15) represent the entering and leaving conditions, respectively. When the RSRP of the serving eNB becomes worse than the target eNB by HOM value, the UE is entering the HO region. In the HO region, the UE starts sending measurement reports to a serving eNB. The serving eNB then finds the target eNB. If the RSRP of the serving eNB becomes greater than the target eNB by HOM, the UE stops sending measurement reports to the serving eNB.

$$RSRP_i - HOM < SINR_{TH}, \tag{14}$$

$$RSRP_i + HOM > SINR_{TH}. \tag{15}$$

The HO decision is taken according to (16) for the duration of a selected TTT, based on the applied algorithm.

$$RSRP_j > RSRP_i + HOM. \tag{16}$$

Optimization of HOM and TTT may shift the HO region to a better radio network operation.

4. Delay

End-to-end delay is the time taken by a packet to travel across a communication network from its source to its destination. Delays may happen at various points in the network, such as delay at the source, delay at the receiver, or delay in the network. Delays due to analogue-to-digital and digital-to-analogue conversion can occur at the source or receiver, or both, while queuing and propagation delays occur in the network due to the “store” and “forward” nature of routing [30].

It is well known that real-time application services are delay-sensitive. So as to maintain QoS, the end-to-end delay needs to remain lower than a certain value and to be constant for as long as possible. In this paper, as recommended in [31], the exponential/proportional fair (EXP/PF) algorithm was chosen as the packet scheduling algorithm for the video streaming service. As the load increases, the EXP/PF algorithm is able to sustain the performance for real-time service in terms of average throughput and packet loss ratio.

IV. Results and Discussion

An LTE scheduler is allocated RBs at every 1 ms transmission time interval (TTI), depending on the type of scheduler implemented. In SFRAMP, the UE selects the better signal quality among the reused sub-bands. To achieve seamless HO procedures and quick HO decision, a scheme having the best SINR and fastest link-failure recovery time has been proposed. The former can be achieved by mitigating ICI, especially at the cell boundaries of the HO area. SFR is the most effective way to achieve the best SINR for the outer cell users. On the one hand, it provides a highly efficient bandwidth utilization with an FRF close to one, as shown in Fig. 1; but on the other hand, SFR may degrade the SINR for inner cell users since the inner cell frequencies of the source eNB, f_2 and f_3 (in the center of Fig. 1), respectively overlap with the outer cell frequencies of the neighboring cells, f_3 and f_2. The improvement of SINR in the outer cells is almost linear with UE moving outward, while the degradation of SINR in the inner cell is logarithmic due to the arrangement of power allocation in SFR. The logarithmic degradation is not considered significant compared with the advantage of the linear increase of SINR at the HO area [20]. The outer cell throughput will increase following the SINR curve, but this is not within the scope of this paper. The fast link-failure recovery is achieved through the MP procedure that has been described in section II. The MP procedure is unlike the SHO procedure, where all the UE contexts are forwarded to the two neighboring eNBs simultaneously. Forwarding all the UE contexts will reserve the RBs from the two neighboring eNBs, thus, doubling the RBs needed to be assigned to a UE, which in turn results in radio resource wastage and an increase of ICI.

In this paper, the eNB in Fig. 2 performs an SFRAMP HO, which is a hybrid method of MP of HO and SFR. MP is a new LTE HO feature in which the serving eNB may initiate handover procedures with multiple target eNBs (one of which will eventually be activated). MP starts upon reception of the “RELEASE RESOURCE” message, whereby the source eNB will trigger a “cancel” procedure toward each of the nonselected prepared eNBs. A system-level LTE-Sim simulation [32] has been used for the simulation work.

The signal quality can be used for both cell reselection and HO. The time spent searching for a cell can be shortened if the received signal quality is higher than the threshold of cell detection. Further reduction of delay and outage have been achieved by way of MP, whereby UE reestablishment delay is also reduced, as illustrated in (6). In SFRAMP we demonstrated that the delay a UE may experience, due to connection failure, is reduced.

The impact of the LTE handover procedures on the overall user experience depends very much upon the type of application used. For example, a short interruption in service during a long file transfer protocol (FTP) session (for example, large file download) may be tolerable, while an interruption in a VoIP call, a streaming video session, a short FTP session (for example, image download), or a latency sensitive gaming application, may not be [33]. This is the reason why in the following simulations a video application was chosen to represent the UE receiving the DL. In the simulations, all UEs are assumed to be distributed uniformly in the cell. The channel model in the simulations includes the path loss and interference effects. The simulation parameters are shown in Table 1.

In Fig. 5, the simulation results demonstrate that SFRAMP provides a more reliable HO compared to the HHO. The high outage probability in the HHO, stemming from the absence of any ICIC, leads to high interference, especially at the cell borders. Even by applying FFR as an ICIC mechanism so as to reduce ICI (as described in [16]), the reduction of ICI is achieved at the cost of the availability of RBs.

On the other hand, in [7], despite the fact that none of the ICIC mechanisms were applied, FRF was one. The outage probability was reduced by taking advantage of the macroscopic diversity, but this came at the expense of increased ICI. SFRAMP has been shown to outperform previous works. By applying SFR, a more flexible RB utilization can be obtained and ICI can be mitigated at the outer cells, though at the expense of an increased ICI in the inner cell. The inner cell is almost a non-HO region and, as shown in Fig. 4, the increase in ICI in this area is logarithmic [20]. MP implementation provides high link utilization, due to multiple RRC connections, that in turn helps reduce the number of ping-pong HOs. This helps to lower the outage probability. The significance of MP is that, because of multiple RRC connection requests, HO delays will be minimized if the preferred target eNB connection fails. Moreover, the multiple

Table 1. Simulation parameters.

Parameters	Values
Bandwidth	5 MHz
Number RBs	25
Subcarriers per RB	12
Number of subcarriers	300
Subcarrier spacing	15 kHz
Carrier frequency	2 GHz
Duration of simulation	300 s
Frame structure	FDD
Traffic models	Real-time (video streaming) bit rate: 242 kbps [32], [34]
Mobility model	Random direction
UE speed	3 km/h, 60 km/h, 120 km/h
Cell layout	1 km
Max delay (end-to-end)	0.1 s
Subframe length (TTI)	1 ms
Number of cells	7
Number of UEs	20
Propagation model	Macro-cell urban model

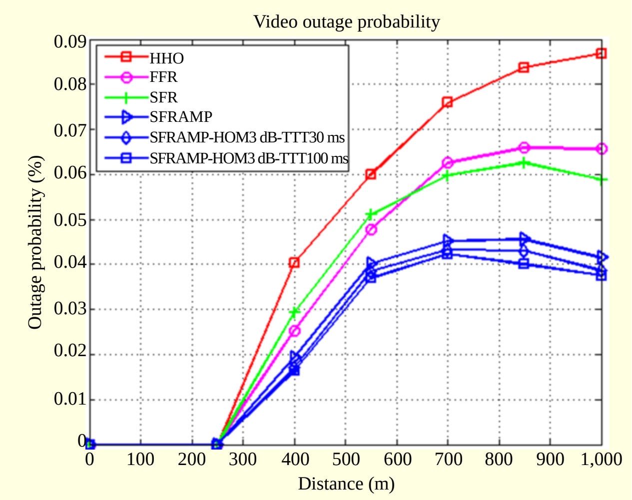

Fig. 5. Outage probability vs. distance at 120 km/h.

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RRC messages contain only the UE context information (the necessary control information and commands: UE identities, UE security parameters, and UE mobility state) thus some resources would inevitably be wasted. These multiple RRC messages do not forward user data that would otherwise occupy twice the number of RBs necessary for data forwarding. However, MP will increase the signalling overhead, which in turn would lead to increased ICI. This ICI could be combated by using SFR. Thus, by taking advantage of the SFR and MP HO schemes, the weaknesses inherent in the previous methods can be overcome.

Figure 5 illustrates that outage probability is increased when a UE moves toward an outer cell. This is because as the UE moves further away from the eNB, its SINR will degrade due to the increased path loss. The FFR or ICIC can give a lower outage probability than the SFR before getting to the geometric threshold value that divides the cell into the inner and outer parts. This is because in FFR both the inner and outer cells' transmit power is fixed and equal to the total eNB transmitted power, whereas in SFR the inner cell transmit power is designed to be lower than that of the outer cell. Thus, FFR has the ability to improve the SINR at the inner cell where the reuse factor is one and at the outer cell where the reuse factor is three, but this comes at the expense of wasted RBs. The geometric threshold in this scheme is at $r = 650$ m. In contrast, the SFR performs much better at the outer cell when the position of the UE is beyond the geometric threshold. This is due to the non-occurrence of ICI, a result of there being no conflict in the allocation of RBs, and the linearity of the SINR improvement.

As has been highlighted in the previous paragraph, in SFR, the outer cell transmit power is designed to be higher than that of the inner cell. In addition, the sum of their respective powers should not exceed the total eNB transmit power. The FRF for SFR, shown in Fig. 1 on the right-hand side, is almost one; thus, SFR can improve the SINR of the outer cell with a more efficient RB utilization, but at the expense of increased inner-cell ICI. Combining SFR with MP can combat ICI and minimize the delay that occurs when a UE fails to obtain a connection to the desired target eNB.

The optimization of the HO parameters can provide more enhancements to the HO procedures, as explained in section II. It can be seen that picking the right combination of HOM and TTT can decrease the outage probability. This is because tuning the HO parameters will improve condition (16) and prevent a UE from performing an unwanted HO, known as a ping-pong effect, arising from a sudden signal fading or shadowing.

For Fig. 5, the UE speed is set at 120 km/h in random directions. The higher speeds will cause more frequent HOs; therefore, HO performance will be more critical, especially for real-time services. Other simulation parameters are presented in Table 1.

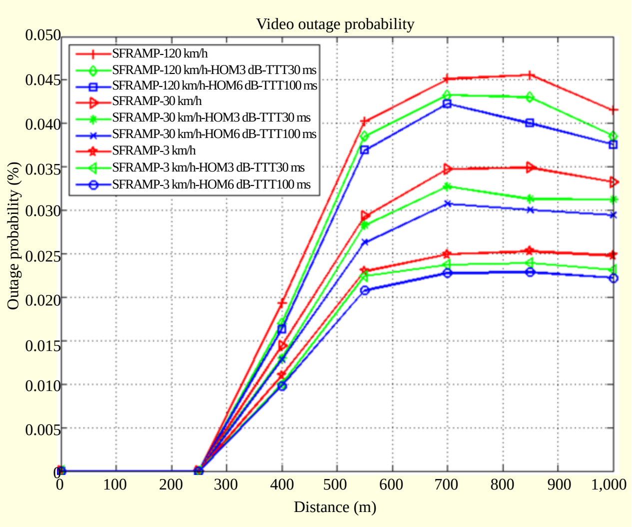

Fig. 6. Outage probability vs. distance at different speeds.

Figure 6 illustrates that lower mobility produces lower outage probability, which is due to the easy maintenance of radio links at lower speeds. It is clear that the outage probability is almost constant at a UE speed of 3 km/h. The proposed approach has been evaluated and compared at the different UE speeds of 3 km/h, 30 km/h, and 120 km/h. It can be observed that SFRAMP gives a lower outage probability even with high mobility.

The maximum outage probability is 0.04556 at 850 m, which is the center of the outer cell. Interestingly, the outage probability is lower at 1,000 m than at 700 m. This stems from the linear increase of the SINR at the outer cell, as well as the availability of RBs since frequency reuse is almost one. The HOM was chosen to be 3 dB and 6 dB and the TTT to be 30 ms and 100 ms.

Figure 7 shows that the delay in HHO is high and increases with load. This is one reason why a hybrid method was proposed, even though HHO is less complex. The proposed SFRAMP method gives much less delay than that of the HHO because it takes advantage of MP. When a target eNB fails to connect with an incoming UE, the UE has already reestablished an RRC connection, as explained in Fig. 3. The establishment of the RRC connection is a reflection of a UE's transition from RRC idle mode to RRC connection mode.

Before obtaining this connection, a UE cannot transfer any application data. The sending of RRC connections, the consequent procurement of admission control permission, and then the resending of the acknowledgement from the target eNB to the UE so as to update the UE, all results in a delay — the kind of which can be eliminated through alternative MP

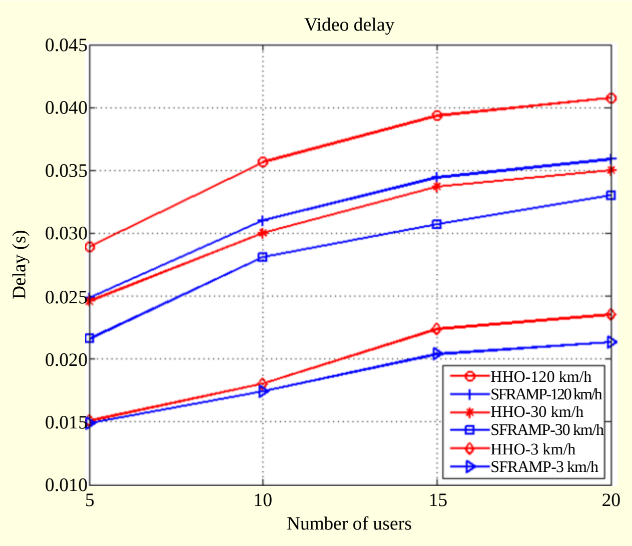

Fig. 7. Packet delay vs. number of users with different speeds.

connection. Typically, the process for completing the RRC Connection Setup messages takes two seconds [2]. It can be seen from Fig. 7 that lower UE speeds give less delay. This is because at higher speeds the radio link quality will be weakened due to Doppler shifts. The reason for large delays at full load, when the number of users is 20, is attributed to the congestions in the network. In this case, it is shown that SFRAMP is more effective than HHO for high speeds in terms of delays. This is due to its ability to strengthen the quality of the radio link by means of SRF and MP (these help minimize the search time by $n \times T_{\text{search}}$ ms).

V. Conclusion

In this paper a new method has been proposed to improve the handover procedures and minimize end-to-end delays. Simulation results show that the proposed method, called SFRAMP, outperforms those of previous works. It was demonstrated that this scheme can significantly reduce outage probability by improving HO procedures. The main contributions of this work are on choosing the proper geometric threshold, improving signal quality by means of SFR, and reducing delay through MPs. The high reduction of outage probability obtained at the outer cell stems from two reasons: a linear increase in SINR and the establishment of multiple RRC connections. Furthermore, SFRAMP also minimizes end-to-end delays with various UE speeds due to the elimination of waiting time in the setting-up of RRC connections. This is because the outer cell SINR improves almost linearly, while the degradation of the UEs in the inner cell is logarithmic. As the throughput is proportional to the SINR, the outer cell throughput will likewise increase, thus, resulting in an increase of the total system throughput as well. This has been well reported in earlier works [9]–[15]. The SFRAMP gain in outage probability has been shown to be approximately 24.4% over the HHO. Also the improvement in SFRAMP gives a reduction of end-to-end delay by approximately 11.9% at full load compared to the HHO. These gains become more significant when the HO parameters, HOM and TTT, are implemented. In addition, the proposed scheme provides efficient frequency utilization due to the full bandwidth utilization, which is a plus for LTE networks. In future it is planned to use a dynamic geometric threshold to improve the HO procedures and to provide load balancing as well.

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