Mobility Management for novel LTE-A Relay System

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***Abstract*—In a conventional cellular network, user equipment (UE) is connected directly to a base station (BS), and when a user moves away from the cell center, he gets less bandwidth and lower data rates. However, a relaying technique has been introduced in 3GPP release 10 & 11 to allow establishing an indirect two-hop link between UE and BS through a relay node (RN). RNs can also be used to spread the cell coverage and increase coverage at the cell edge outside the main area. This paper focuses on mobility management for the LTE-Advanced cellular network where UEs and RNs are connected through a WLAN connection.**

Keywords—Heterogeneous network, LTE-A, WLAN, Fixed and Mobile Relay, Vertical Handoff

I. INTRODUCTION

The increase in demand and rapid development of wireless communication quality over the past three decades has motivated the 3rd Generation Partnership Project (3GPP) to introduce the Long-Term Evolution (LTE) and LTE-Advanced cellular networks. LTE and LTE-A include new capabilities to offer sufficient performance to support good quality IP-based streaming video and other multimedia services over IP to a large number of customers, simultaneously. One of the LTE challenges is to increase the capacity of networks as well as reduce the cost/bit delivered in order to address the explosive growth in data demand. Heterogeneous network (HetNet) represents a promising solution for the need to increase spectral bandwidth, increase efficiency, and improve mobility support [1].

In a heterogeneous network, various small cells are distributed throughout the macro cell network, which includes micro eNBs, pico eNBs, femtocells, and relay nodes [1]. This research deals with relay nodes (RNs) that can extend the LTE radio access technology with support for relaying functionality (Fig. 1). With relaying, the mobile terminal communicates with the network via an RN that is wirelessly connected to a macro cell using the LTE radio interface technology [2]. The base station (BS) may serve one or several relays in addition to directly serving mobile terminals [2]. With the 3GPP relaying solution [3], RNs will appear to mobile terminals as ordinary cells; however, when using the WLAN relaying solution, the mobile terminal needs to have two different interfaces in order to be able to support the services offered by the LTE-A and WLAN cells [4]. A switching mechanism between the two interfaces is therefore required for mobility between the LTE-A macro and WLAN relay cells.

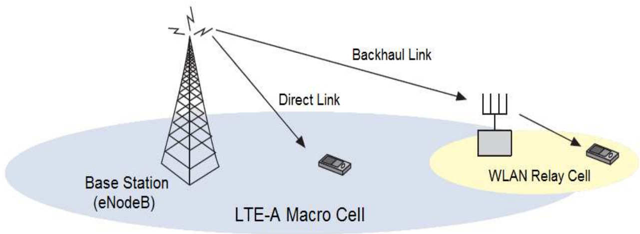

Fig. 1. LTE-A relay solution using WLAN

The two major challenges addressed in this context are to maintain the throughput and ensure seamless mobility and service continuity to all mobile terminals. Hence, the objective of this paper is to develop and evaluate an intelligent vertical handoff algorithm for the LTE-A relay system focusing on throughput and service continuity. Specifically, the paper addresses the relaying LTE-A/WLAN and mobility management of a heterogeneous network.

The paper is organized as follows. First, an overview of fixed and mobile relay systems is given in Section II. Section III presents a handoff analysis model. Simulation and results are described in Section IV, and conclusions are presented in Section V.

II. HANDOFF AND WLAN RELAY FOR LTE-A

A. Fixed and Mobile Relay

One of the attractive features of RNs is the LTE-based wireless backhaul, as this can provide a simple method of deployment to improve coverage to dead zones (e.g., at cell edges) and, more importantly, traffic hot zones [1, 2]. The donor-relay link may operate on the same frequency as the relay-terminal link (inband relaying) or on a different frequency (outband relaying) [2]. Relay stations can be classified into fixed and mobile relay stations according to the mobility situation of the relay station [5], as illustrated in Fig. 2.

Fixed relay is usually used to cover hot spots and increase cell edge throughput. In LTE-A, the average user throughput is not improved as much as the peak rate [6]. A relay system may be made mobile by equipping it to vehicles (e.g., buses, trains) to increase throughput and decrease handoff interruption for passengers. High traffic and user concentration are expected in this case since vehicles are relatively crowded, and passengers are more likely to use high data rate services (e.g., browsing,

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gaming) to kill time [6]. In the remainder of this article, we use RNs to mean both fixed and mobile stations.

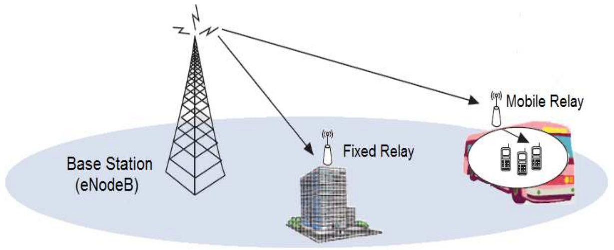

Fig. 2. Fixed and mobile relay

B. *WLAN Relay for LTE-A*

One of the 3GPP relay requirements is to support different air interface technologies such as 3G and WLAN on an access link (RN-MT) [7]. Coupling WLAN cells to the LTE-A network at the RN level is known as the interconnection architecture "Tight Coupling" [8]. The most attractive qualities when using WLAN as an air interface on the access link are having the opportunity to serve all mobile terminals without subscribing to the operator owner of the backhaul link, which leads to optimize the number of RNs instead of having different relays for each operator. Second, an increase in served mobile terminals is achieved when using multi-hops network forming the wireless mesh networks (WMNs) (RN acts as a WMN access point). Our study takes into consideration WLAN as an air interface and with two-hop RNs.

C. *Handoff for LTE-A/WLAN Relay*

Mobility management is essential in ensuring service continuity during handoff or handover (HO). HO is the procedure that allows a terminal to maintain a call or session while moving between cells [8]. HOs can be classified into horizontal and vertical [9]. Horizontal HOs used in traditional cellular networks allow the mobile terminal to move between cellular network cells. Vertical HOs, on the other hand, are specific to heterogeneous networks, in which mobile terminals move among different technology cells (e.g., HO between LTE-A and WLAN cells).

The HO is usually transparent to the user, but it directly affects the quality of service. A considerable amount of research has been done on horizontal HOs (in cellular networks) and vertical HOs (between cellular networks and WLAN) [10]. However, new HO-related issues arising when WLAN RN is added should be carefully investigated since the network architecture changes and becomes more complicated.

There are several vertical HO algorithms in the literature. Reference [9] proposed a HO decision algorithm using the receive signal strength (RSS) metric; however, RSS has not given good results particularly in heterogeneous networks. Further, [11], [12], and [13] tried to combine RSS with other metrics. The evaluation metrics to make HO decisions used are distance between mobile terminal and base station, velocity of terminal, and cost of service, which makes the algorithms more complex with concomitant high delays and energy consumption [14].

The work developed by [15] proposes a vertical HO decision algorithm based on signal-to-noise ratio (SNR) and traffic type metrics, with the goal of maximizing network throughput and reducing the ping-pong effect. Reference [16] has also developed a QoS-based vertical HO.

Reference [14] proposes a vertical HO decision algorithm that uses the combined effects of signal-to-interference-noise Ratio (SINR), user required bandwidth, user traffic cost, and participating access networks to make HO decisions for multi-attribute QoS considerations.

The work closest to the proposed solution is that presented by [15]. Despite the use of the WLAN SNR mapping method before starting the HO process and verifying the triggering condition, the algorithm uses a strongly enhanced mechanism to reduce unnecessary HOs. However, this solution does not take into account the mobility of WLAN RN and strategies for selecting RNs at the time of decision. Using just SNR and type of service as HO conditions is insufficient to meet user needs and maintain quality of service. Furthermore, this solution does not use SINR as a metric of HO decisions, which means that interferences are ignored.

III. Handoff Algorithm

A. *Triggering Condition*

The aim is to develop a simple implementation of the proposed solution for mobile terminals, offering a high throughput and low packet loss. The proposed HO algorithm is controlled by a type of mobile terminal controlled HO (MCHO). Since this study concentrates on the mobility management in a heterogeneous LTE-A/WLAN network, we focus solely on vertical HO.

As shown before, the SINR metric can give more details on the channels status. Hence, the proposed algorithm considers the received SINR with dynamic threshold (H) and a timer (ΔT) as presented in (1) and (2):

Condition for downlink HO (eNB to RN):

$$SINR_{RN} - SINR_{eNB} \succ H \text{ for } \Delta T \tag{1}$$

Condition for uplink HO (RN to eNB):

$$SINR_{RN} - SINR_{eNB} \prec H \text{ for } \Delta T \tag{2}$$

where $SINR_{eNB}$ and $SINR_{RN}$ are the signal-to-interference-noise ratio for LTE-A and WLAN network, respectively. With the use of (1) and (2), the algorithm can take the proper decision to handoff attaining higher throughputs and lower packet loss as well as minimizing the number of HOs taking place.

B. *SINR Calculation and Data Rate Estimation*

To verify the HO condition, the algorithm should calculate the received SINR from eNBs and RNs. As described in [14], the SINR can be calculated as follows:

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SINR from eNB:

$$SINR_{eNBj,i} = \frac{G_{eNBj,i} P_{eNBj}}{P_B + \sum_{k \in eNB} (G_{eNBk,i} P_{eNBk}) - G_{eNBj,i} P_{eNBj}} \quad (3)$$

where P_B is the power of the noise at the terminal level, P_{eNBk} is the total power transmitted by eNB_k, $P_{eNBj,i}$ is the power transmitted by eNB_j to mobile terminal (i), and $G_{eNBj,i}$ is the channel gain between eNB_j and mobile terminal (i).

SINR from RN:

$$SINR_{RNj,i} = \frac{G_{RNj,i} P_{RNj}}{P_B + \sum_{\substack{k \in RN \\ k \neq j}} G_{RNk,i} P_{RNk}} \quad (4)$$

where P_{RNk} is the total power transmitted by the relay node RN_k, $P_{RNj,i}$ is the power transmitted by RN_j to mobile terminal (i), and $G_{RNj,i}$ is the channel gain between RN_j and mobile terminal (i)

To estimate the data rate, Shannon's theorem gives an upper bound to the data rate in terms of the bandwidth and signal-to-interference-noise ratio. Based on this theorem, the data rate can be calculated as presented in (5) and (6):

$$R_{eNB} = W_{eNB} \log_2 \left(1 + SINR_{eNB}\right) \quad (5)$$

$$R_{RN} = W_{RN} \log_2 \left(1 + SINR_{RN}\right) \quad (6)$$

where R_{eNB} and R_{RN} are the maximum theoretical channel data rates for LTE-A and WLAN network, respectively; W_{eNB} and W_{RN} are the bandwidth of LTE-A and WLAN links, respectively,

C. Dynamic Threshold

Figure 3 below shows an HO scenario, whereby a UE is connected to LTE-A eNB. It moves in direction of WLAN RN while in a call.

In Figure 3, it is assumed that terminal is connected to eNB, which has a stable data rate. Let R_{Ref} be a reference data rate calculated by the terminal every ΔT period of time:

$$R_{\mathrm{Re}f} = \frac{1}{\Delta T} \int_{\Delta T(\lambda)}^{\Delta T(\lambda+1)} R_{received}(t)dt \,,\ \lambda = \{0,1,2,....\} \quad (7)$$

where $R_{received}$ is received data rate and λ is coefficient of ΔT. The default value of the reference rate is the eNB data rate.

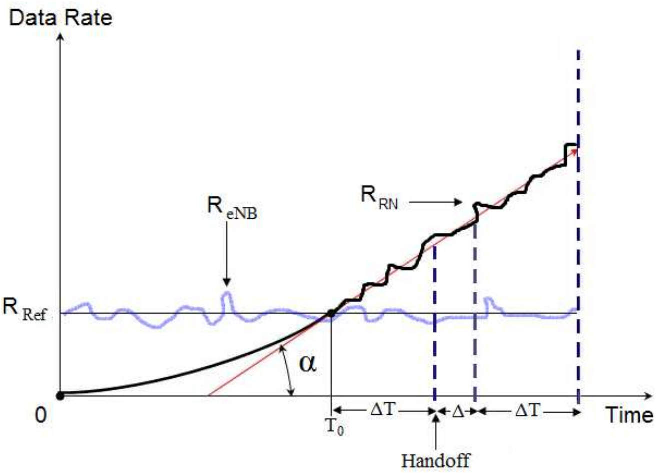

Fig. 3. Scenario of downlink HO

Let R_{RN} and R_{eNB} be data rates for RN and eNB, respectively. Let T_0 be a time where (8) is verified:

$$\frac{R_{RN}(T_0)}{R_{\mathrm{Re}f}} \geq 1 \quad (8)$$

Since the HO algorithm is proactive, once (8) is verified, the mobile terminal starts to assess the HO opportunity by estimating the relative velocity between the mobile terminal and RNs for each period of time ΔT.

To take into consideration the mobility metric in HO decision, a mobility parameter **Ω** is considered and defined as follows:

$$\Omega_i = Tan(\alpha_i) = \frac{R_{RNi}(T_0 + \Delta T) - R_{\mathrm{Re}f}}{\Delta T} \quad (9)$$

where $\mathbf{\Omega}_i$ and α_i are the mobility parameter and angle of data rate variation for RN_i during a period of time ΔT, i= {1…N}, and N is the total number of RNs

To achieve the design goal, the dynamic threshold is defined as

$$H = \alpha - m\left(\frac{R_{RN}}{R_{eNB}}\right)_{dB} + n\left(1 + \Omega^2\right)_{dB} + k\beta \quad (10)$$

where α and β are the coefficients for the margin H adjustment. For non-real–time service (NRTS), m = 1 and n = -1; for real-time service (RTS), m = 0 and n = 1; k=0 for downlink HO and k=1 for uplink HO.

For NRTS, packets arrive in bursts and are not sensitive to delays. The user throughput becomes the first metric taken into consideration in the HO decision. If the throughput ratio of RN and eNB is becomes large and mobility the parameter is low, it

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reduces the dynamic threshold and downlink HO will be easier. On the other hand, for RTS, packets are sensitive to delays and mobility of RN. Hence, the dynamic threshold will be adapted with the mobility parameter to favor a stable throughput and less mobility.

D. *Relay Nodes Selection*

The RN selection process is based on mobility and service type. For NRTS, the algorithm will choose an RN offering a higher data rate with lower mobility. In the case of RTS, the algorithm will choose an RN with low mobility and the most constant data rate in order to guarantee the data rate R_{RTS} required by the application.

The objective is to find the optimal candidate RN_k, which will verify (11) for NRTS and (12) for RTS:

$$\begin{cases} k = \arg\max\limits_{i=\{1..N\}} \dfrac{R_{RN_i}}{R_{Ref}} \quad and \\ k = \arg\min\limits_{i=\{1..N\}} \Omega_i^{\,2} \end{cases} \tag{11}$$

$$\begin{cases} k = \arg\min\limits_{i=\{1..N\}} \left(R_{RN_i} - R_{RTS}\right)^2 \quad and \\ k = \arg\min\limits_{i=\{1..N\}} \Omega_i^{\,2} \end{cases} \tag{12}$$

Algorithm 1 Relay nodes selection

Assumption: The mobile terminal is connected to eNB
If (NRTS) and ($R_{RNi} > R_{Ref}$)
For each RN_i
Calculate (R_{RNi} / R_{Ref})
Calculate (Ω_i)
End
Then select most profitable RN_i as candidate for HO
If (RTS) and ($R_{RTS} \geq R_{Ref}$)
For each RN_i with ($\Omega_i > 0$)
Calculate (R_{RNi} / R_{Ref})
Calculate (Ω_i)
Then select the most profitable RN_i as a candidate for HO

E. *Timer and Reduce Unnecessary HO*

As presented by [15], to reduce unnecessary HO and to avoid the ping-pong effect, the strategy is to verify for each HO if the duration of ΔT after HO (during which the throughput is higher) is big enough with respect to the period 2Δ transition; then the HO is justified. (Δ is the HO treatment time where no data is acquired). Therefore, the mobile terminal verifies (13) and (14) before each HO.

$$\int_{T_0+\Delta T+\Delta}^{T_0+2\Delta T+\Delta} R_{RN}(t)dt \succ \int_{T_0+\Delta T}^{T_0+2\Delta T+2\Delta} R_{eNB}(t)dt \tag{13}$$

$$\Delta T \geq \frac{2\Delta}{\Omega^2+1} \tag{14}$$

Indeed, the trigger times ΔT is the dynamic period, which is computed at each interval based on the new SINR measures.

IV. SIMULATION AND RESULTS

The performance of the proposed HO algorithm has been evaluated with a scenario of 4 eNodeB and up to 20 RNs. The maximum eNB and RN power was 43 dBm and 30 dBm, respectively. The simulated environment was outdoors with UE and RN in the mobility model displaced randomly at a fixed speed of 0.5 and 2 meters per second respectively. Figure 4 shows the LTE-A with WLAN RN networks. The performance is compared to RSS and SNR as defined in [15]:

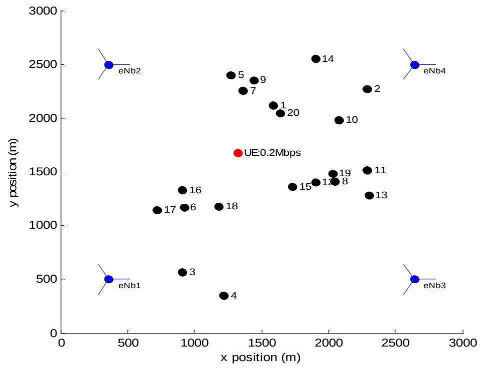

Fig. 4. Network simulation model

A. *Throughput for Non-Real–Time Traffic*

Figures 5 and 6 show the received throughput with respect to time for three algorithms: RSS, SNR, and the proposed algorithm.

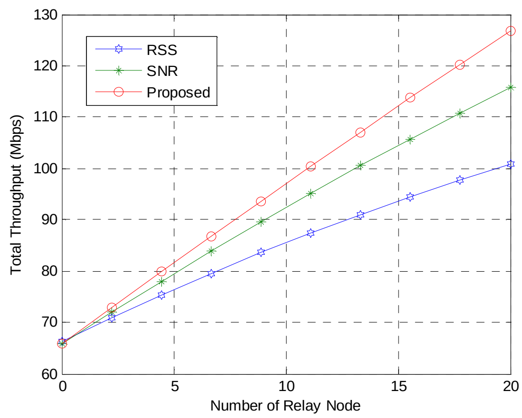

Fig. 5. Total throughput per RN concentration

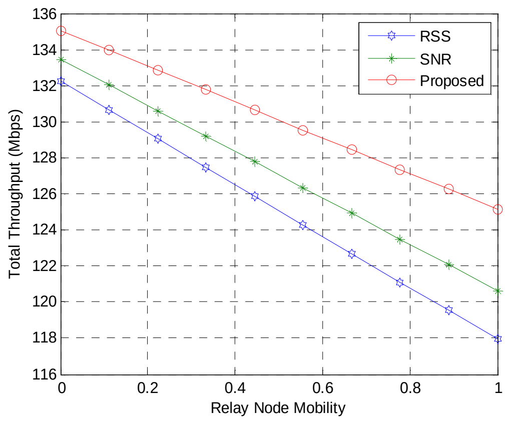

Fig. 6. Total throughput per RN mobility

Figures 5 and 6 show how the received throughput is affected by the number and mobility of RNs, respectively. In both graphs, the proposed algorithm curve is clearly positioned above those of RSS and SNR. Hence, the proposed algorithm can reach higher throughputs under the same network conditions than that with both RSS and SNR.

B. *Packet Loss for Real-Time Traffic*

Figures 7 and 8 depict the comparative packet loss performances for RSS, SNT, and the proposed algorithm.

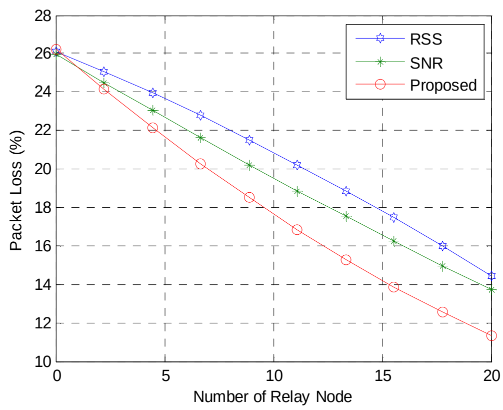

Fig. 7. Packet loss per RN concentration

Figure 7 shows how packet loss can be reduced when increasing RNs in the LTE-A network; however, the mobility of RNs does directly affect the packet loss metric, as illustrated in Figure 8. It can be seen the packet loss rates of RSS and SNR algorithms tend to be the similar, with high packet loss as compared to our proposed algorithm, which clearly minimizes the lost packet.

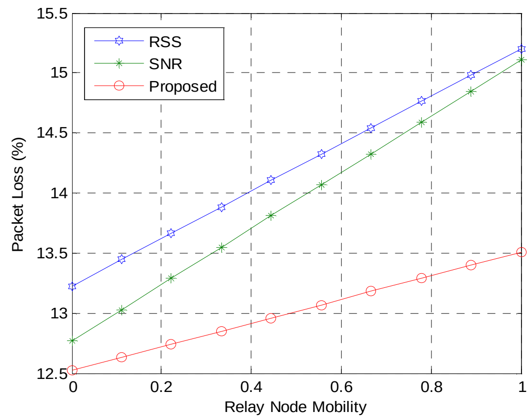

Fig. 8. Packet loss per RN mobility

C. *Performance of Ping-Pong HO*

Figures 9 and 10 show the number of HOs when users move around the network with different levels of RN concentration (Fig. 9), from fixed to high mobility RNs (Fig. 10). It can be seen that the increment in RNs increases the HO rate since it offers more opportunities for the mobile terminal to be handed over to an RN. The performance of our algorithm is clearly better than SNR and RSS. This performance can be explained by (10) and (13).

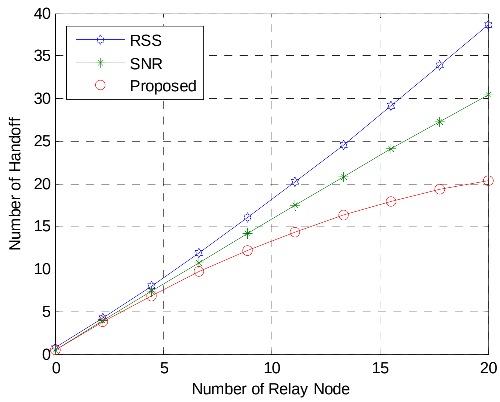

Fig. 9. Number of HOs per RN concentration

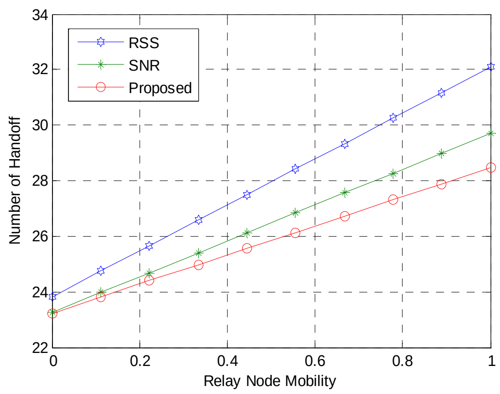

Fig. 10. Number of HOs per RN mobility

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D. eNodeB and RNs Utilization

Figure 11 illustrates the direct eNodeB access utilization rates for each analyzed algorithm.

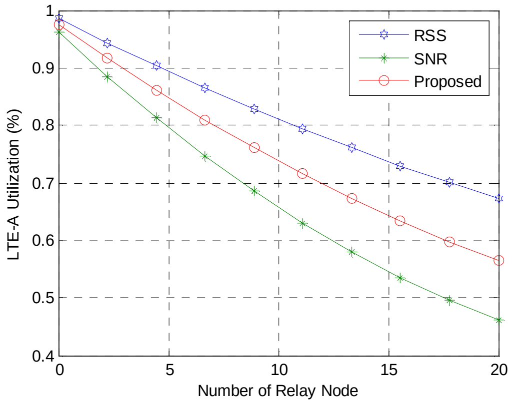

Fig. 11. Utilization of eNB direct access

Figure 11 shows that the increment in RNs decreases the utilization of direct eNB access. Our proposed algorithm fits between RSS and SNR, between low and high RN utilization, respectively. In a scenario of 20 mobile RNs, the proposed HO algorithm uses direct eNB access less than 60% of the time (for the remaining 40% of the time or more, UE will be connected to RNs using the WLAN interface).

From the overall results, it is clear that the proposed algorithm offers better performance than both the RSS and SNR algorithms. This is because it takes into consideration the SINR and mobility of RNs along with a mechanism to avoid the ping-pong effect.

V. Conclusion

Relaying provides an attractive means of coverage extension and throughput enhancement. 3GPP has already started supporting relays nodes in LTE-Advanced networks. In this paper, we propose a novel relay scheme using WLAN as the access link. Performance of this has been evaluated in terms of throughput and packet loss. Also, in this paper, we have investigated the HO problem in LTE-A networks with mobile and fixed WLAN relay stations. We have proposed a novel vertical HO algorithm, which has been evaluated and compared to existing algorithms. We have shown that better HO performance can be achieved by selecting a reference data rate to trigger the HO mechanism. We have also shown that our proposed vertical HO algorithm performs in different mobility scenarios (low and high mobility) and RN concentrations in terms of throughput and packet loss with the minimum HO so as to reduce the ping-pong effect.

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