An Improved Handover Algorithm for LTE-A Femtocell Network

Olusegun O. Omitola[1,2] and Viranjay M. Srivastava[1]
[1] Department of Electronic Engineering, University of KwaZulu-Natal, Durban – 4041, South Africa
[2] Department of Electrical, Electronic and Computer Engineering, Afe Babalola University, Ado-Ekiti, Nigeria
Email: omitolasegun@gmail.com; viranjay@ieee.org

Abstract—Femtocells have been regarded as low-power and low cost devices for enhancing the capacity and performance of mobile cellular networks. Apart from forming a two-tier network with the macrocell to offload traffic from the macrocell, femtocells can be deployed in an urban area to achieve more data rate with better Quality of Service (QoS). However, this is at the expense of increased frequency of the handover of the UEs from one femtocell to another femtocell. Selecting a particular femtocell for handover is a serious challenge in a femtocell/macrocell deployment environment. Similarly, managing the resulting handovers can be extremely difficult. Thus, this study presents an algorithm to improve handover in LTE-A femtocell network. The complexity of the algorithm was determined and the performance by comparing it with existing algorithm in terms of number of handovers and the ratio of target femtocells. The results have shown that the proposed algorithm outperformed the existing algorithm.

Index Terms—Femtocell, cellular networks, macrocell, QoS, handover, LTE-Advanced

I. Introduction

To increase the capacity and for better quality of service, enhancements have been made to the LTE in the LTE-Advanced framework. The LTE-Advanced was designed to meet the ITU standards for IMT Advanced, which is *100 Mbps* data rate for mobile users and *1 Gbps* for users with low or no mobility. Other requirements for 4G by ITU include general acceptance of functions with support for advanced cost effective multimedia services and applications, compatibility of services with fixed network, internetworking, high quality service for user devices, universal user equipment acceptability [1], user-friendly applications and services, and global roaming capabilities. The goals of cellular network include providing a fast seamless handover from one cell to another. This is very important in maintaining ongoing service during the handover procedure and to prevent service loss due to low signal from a particular base station or due to the mobility of users from one cell or base station to another. Also, performance is degraded if data transfer is delayed during the handover procedure. Therefore, it is important that the handover should occurs seamlessly to prevent an ongoing service (or call) from being dropped or experience ping-pong effect [2] that is frequent movement of User Equipment (UE) from one cell or base station to another as a result of the UE's mobility and multiple low power base stations in LTE-Advanced networks. Careful consideration is required in designing LTE-Advanced involving macro and smaller base stations such as femtocells to reduce associated handovers. Usually, femtocell is positioned in LTE-Advanced network in a way that enables it to operate independently of the backhaul type and connect to an operator's network through internet connection thus eliminating the cost associated with deployment of huge macrocells [3]-[5]. A femtocell provides cost-efficient ways of enhancing the capacity of the cellular system as well as improving the performance especially at the cell edge. As low-cost, low power and energy-efficient base stations, they can be easily installed and managed [6], [7]. In 3GPP, the femtocell base station is known as the Home E-node B (HeNB) and provides the Radio Access Network (RAN) functions [8].

The procedure for handover and mechanism supporting user's mobility in 4G LTE networks have been described in [9], [10]. *Ulvan et al*. [11] studied these procedures and introduced the user equipment mobility prediction to achieve a more optimized procedure. This mobility prediction depends on Markov chain probabilities in order to determine the present position and the velocity as well as the direction of the UE. The authors proposed reactive and proactive handover strategies to reduce the frequent and unnecessary handovers. In [7], the reactive handover decision strategy and mobility prediction proposed in [11] were used to investigate the handover procedure in both the horizontal and the vertical handovers. The authors explained that proactive handover can occur before the current base station Received Signal Strength Indicator (RSSI) level reaches the Handover Hysteresis Threshold (HHT) while the reactive handover postpones the handover to as long as possible until the UE fully loses the signal from the source base station. This is similar to the method employed in [12] where UE was forced to stay in a connected femtocell access point. To determine the distance of the next position of the UE in advance, direct movement mobility model was adopted. It was shown that the reactive handover produces the lowest number of

Manuscript received January 2, 2020; revised June 2, 2020.
Corresponding author email: omitolasegun@gmail.com.
doi:10.12720/jcm.15.7.558-565

handovers and latency because of its principle of postponing the handover until the signal is lost. A new criterion like the base station capacity estimation was introduced to the handover procedures in [13]. With this, the base station utilization and type can be determined. This helps in preventing the base station from being overloaded. It also results in better load balancing and improved Quality of Service (QoS) for the users. In this work, the authors present an improved handover algorithm for LTE-A femtocell network to reduce handover in LTE-Advanced femtocell network. One can explain from the literature that most works in this area focus on the handover reduction through various means, however, much has not been done in determining the UE's speed and the complexity of the algorithm together. The few ones that have considered the UE's speed do not determine its Impact/effect on the complexity of the algorithm. Therefore, this work apart from considering the speed of UEs, which help in further handover reduction, determines the complexity of the proposed algorithm with the existing one.

This work has been organized as follows: the system architecture of LTE-Advanced network is presented in section II. Section III discusses various challenges associated with femtocells. An improved algorithm which reduces handover in LTE-Advanced is presented in section IV. This section also discusses the complexity of the proposed algorithm as well as the traffic analysis of the femtocell network. The performance analysis and results were presented in section V. Section VI concludes this work and made recommendations for the future work.

II. System Architecture of LTE-A Network

The LTE-A system architecture in Fig. 1 consists of the femtocell base stations and the macrocell base stations. A macrocell base station is called an eNB and the femtocell base station HeNB. The HeNBs are supported by the EPC which consists of the Serving Gateway (S-GW) and the Mobility Management Entity (MME) [9], [14], [15]. The S-GW functions include routing and forwarding of the packets between the UEs, charging and accounting. It also acts as different anchor points for different handovers. The MME functions include managing the UE access and mobility, the UE bearer path creation as well as performing security and authentication [16]. The LTE-A EURAN architecture also consists of the HeNB-GW which acts as concentrator for the control plane to support large numbers of the HeNBs [17]. The HeNBs and the eNBs on the other hand, perform related functions of terminating the user and control plane protocols. They provide radio control functions, admission control, paging transmission or message broadcasting, routing and scheduling data towards the S-GW [18].

In Fig. 2, the S1 interface is set in the macrocell-femtocell interfaces together with the gateways and units. Communication takes place between the HeNB nodes and the EPC via interface S1-U and S1-MME. The HeNB GW and management system entities perform the function of relaying packets to and from the femtocell stations [19].

The LTE femtocell logical architecture includes an entity called the HeNB GW which functions as the concentrator to support many HeNBs. The HeNB GW connects many HeNBs to the EPC as shown in Fig. 3. Between the HeNB and the CN, the HeNB GW occurs to the MME as eNB and to the HeNB as MME [20].

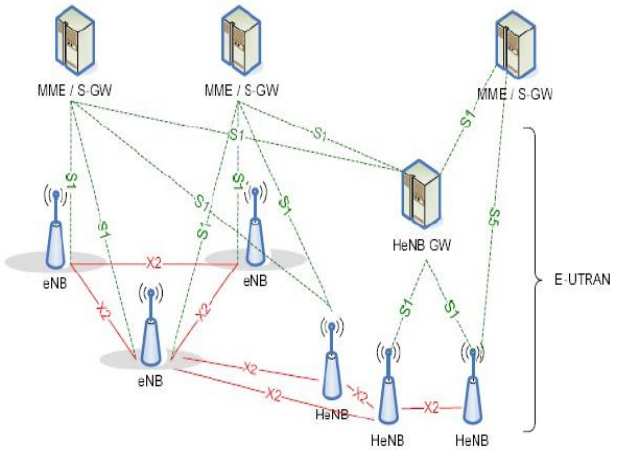

Fig. 1. E-UTRAN architecture with Femtocells [18].

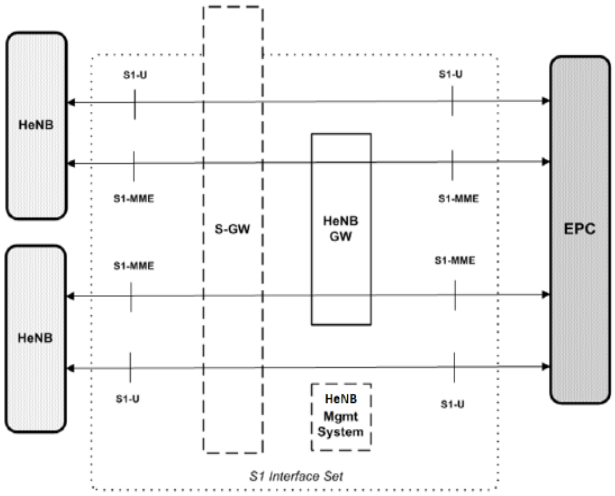

Fig. 2. Macrocell-Femtocell Internal Interfaces for handover process [19].

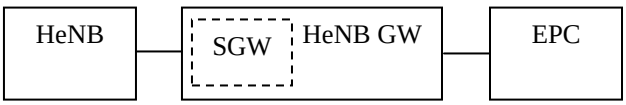

Fig. 3. Logical architecture of femtocell.

III. Femtocell Challenges

A major challenging issue in femtocells is its small coverage area which often causes handover in high dense deployment. Other challenges include interference between femtocells and macrocell, power management, mobility management, mode of operation, timing and synchronization, power management and security etc.

A. Access Mode Challenge

A Femtocell Access Point (FAP) owing to its short coverage can provide services for a limited number of UEs. A Femtocell deployed openly provides services for public UEs although few UEs can only be accommodated. This results in service degradation due to the number of UEs striving to use the resources. When a femtocell is in a closed access mode which is a preferred mode installed by private individuals, the unregistered UEs nearby experiences high signal interference albeit, not having access to the femtocell resources leading to a reduction in the QoS. In [21], the hybrid access mode provides a solution to the interference management problem by allowing unregistered UEs to access the resources of the femtocell while providing services to the registered UEs. However, with this, more registered UEs can be denied access to the femtocell resources as the number of unregistered UEs increases. Therefore, as a way of eliminating this challenge, a FAP should be made intelligent to allow and give priority to the specified number of registered UEs to use the resources [22].

B. Mobility Challenge

Mobility management is one of the important challenges to be addressed in the LTE-A with the femtocell access points which provide low coverage to the users. Due to the low coverage and limited radio resource of the FAP, a large number of neighbour list FAPs is recorded when UEs become mobile. Because of these large numbers of neighbours, it is very difficult to make handover decision. The handover problem can be aggravated by the different types of access mode of the femtocells. Therefore, handover strategy is required to overcome mobility issues in the LTE-A femtocell network and to also ensure that the QoS of the overall network is not depreciated [23].

C. Interference Management

Interference occurs when femtocells and macrocells are deployed within the same frequency band due to non-availability of unused spectrum. This is usually done to increase the spectral efficiency and the network capacity [23]. This deployment type leads to two-tier interference: conventional macro-cellular and user deployed femtocell network [24]. The two-tiered interference can be divided into co-tier and cross-tier interferences as illustrated in Fig. 4 and Fig. 5.

i. Co-tier interference: This interference arises when two FAPs located close to each other operate in the same frequency band. The resulting interference can have a colossal impact on the closed access mode than the open access mode [23]. In the co-tier interference, femto-UEs functions as the source of interference to the neighbour femtocell AP in the uplink while femtocell AP functions as the source of interference to the femto-UEs in the downlink.

ii. Cross-tier interference: This interference arises when the macro-UEs located close to the femtocell AP transmits at high power or when femto-UEs situated close to the macro BS transmits at a low power [25]. The femto-UE acts as a source of interference to the macro BS in the uplink while the femtocell AP acts as a source of interference to the macro-UE in the downlink [26].

These interferences can be reduced by using various interference cancellation and avoidance schemes discussed in [23]. Also, power control schemes can be used to control the noise levels among the neighbouring FAPs and or femto and macro-UEs.

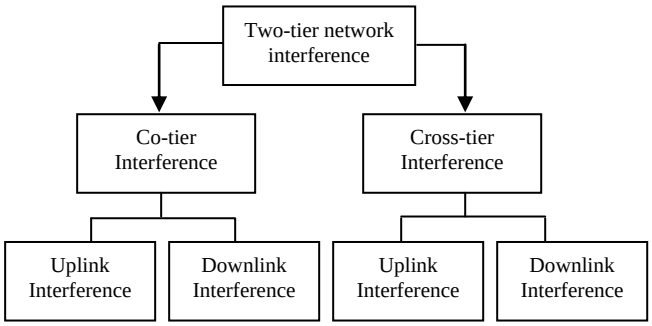

Fig. 4. Interference in two-tier femtocell network [23]

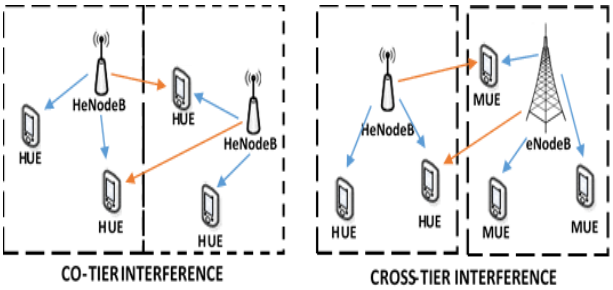

Fig. 5. Co-tier versus cross-tier interference

D. Timing and Synchronization

Timing and synchronization in the femtocell network involves network monitoring usage, tracking security breaches, event mapping, session establishment and termination. In the femtocell networks, attaining time synchronization is very difficult for two main reasons: (i) as the number of femtocell increases, the network becomes denser thereby each femtocell location is unpredictable, (ii) the network provider has little or no control on the location and placement of each femtocell. Solutions to the timing and synchronization problem include incorporating a GPS receiver to the femtocell to provide subscribers with local information [23]. This help to locate and manage interference in the femtocell deployment. In addition, the femtocell can be synchronised with the core network with the help of neighbouring femtocells.

E. Security

This arises mostly when the privately owned femtocell operates in the hybrid mode. Since data traffic will be routed via the owner's internet backhaul, its confidentiality and privacy can be breached. Hackers can use the Denial of Service (DoS) attack to prevent the UEs

from accessing the network by overloading the connection between the FAP and the Core Network (CN). A closed access mode also needs to be protected from unwanted users to prevent them from gaining access to the femtocell resources. The IPSec proposed in [27] can be used with the HeNB Gateway (HeNB GW) to provide a secured link between the HeNB and the core network [28]. The higher the number of deployed femtocells, the more challenging is the security of the network.

IV. Proposed Improved Handover Algorithm

The procedure for admitting calls and the required steps in setting up the connection with the T-HeNB in the proposed algorithm (Fig. 5) can be summarised as follows:

- The UE check its signal level to the SeNB and compared it with a threshold signal (*k1*).
- The UE's speed is determined (i.e. stationary or low speed and mobile UEs) to know whether the UE will hand over to the T-HeNB or will remain in the eNB.
- For the UE to establish connection with the T-HeNB, the signal levels of the other connected UEs to the T-HeNB is checked to ensure that they are not affected below the threshold2 (*k2*).
- UE connects with the T-HeNB provided that the T-HeNB can be accessed openly and has not reached maximum capacity.

A. Algorithm Complexity

The complexity of an algorithm is closely associated with the number of iterations and variables. To evaluate the complexity of the proposed algorithm, the required lines from the algorithm in determining the time complexity can be described as follows.

O(1) – Initialization *//Line 1 to 7*
O(s) – for loop *//Line 8*
O(y) – number of HeNBs *//Line 17, already as y in 6*
O(z) - total number of ListOf HeNB *//Line 19*

Authors have considered two cases to properly evaluate the computational efforts related to the time complexity: one with speed (proposed) and the other without speed (as in existing) and then determine their time complexity. Note that line 15 to 23 in the proposed algorithm is not required in the existing algorithm as the speed of the UE is not considered in the existing algorithm.

Case 1: time complexity of the proposed algorithm,

$$t = O(I) + O(s) \quad (1)$$

While equation (1) represents the time complexity for the best case scenario of the proposed algorithm, equation (2) indicates the time complexity for the worst case scenario of the proposed algorithm where the different speed of the UEs is put into consideration to achieve robustness.

$$t = O(I) + O(s)O((y)*O(z)) \quad (2)$$

Case 2: time complexity for the existing algorithm

$$t = O(I) + O(s) \quad (3)$$

Equation (3) represents the time complexity of the existing algorithm where the speed of the UE is not put into consideration which explains the low complexity obtained in this equation. However, this is not usually the case as the UEs speed are different. Some users/UEs move at a speed less than 30 km/hr while some at more than 30 km/hr. Even though, this matches with the time complexity obtained in equation (1), that is, the best case scenario of the proposed algorithm, the existing algorithm is not robust to handle the different UE speeds.

Algorithm: Procedure for reducing the handover

1. Initialize simulation time *s*
2. Initialize a container *n* holding user calls
3. Threshold = *k1* // *k1* is set threshold signal before handover
4. Threshold *2* = *k2* // *k2* is set threshold signal after handover
5. *ListOf HeNBs = 0* // *list of femtocells or HeNB*
6. y = HeNBs // *number of femtocells or HeNB in considered area*
7. *T-HeNB* // *femtocell with highest signal*
8. For (*i* = 0; i < s; i++) // run for loop until *i* it reaches *s*
9. For each user *x* in *n*
10. Handover Trigger Event
11. Measurement *x* signal level of SeNB to the UE
12. If signal level of SeNB < *k1*
13. Compute the speed of the UE
14. If the speed of the UE < *30*
15. Compute HeNBs signal level measurement, C_{eNB}
16. y=HeNBs.*count()* // *get total* HeNBs
17. for (i= *0*; i<=y; i++) // *generate list of HeNBs in the range of the UE*
18. *ListOf HeNB.add*(HeNB) // *add each HeNB that meets the HeNBs range to ListOf HeNB*
19. *z= ListOf HeNB.count()* // *get total number of HeNB in the list*
20. *foreach (HeNB in ListOf HeNB)* // *identify the HeNB with max signal as T-HeNB.*
21. *If (HeNB signal > k1)*
22. *T-HeNB = HeNB*
23. If max signal level of *T-HeNB > k2 and* Bandwidth capacity available in T-HeNB and can be openly accessed
24. Handover to T-HeNB
25. Remain in eNB //assuming speed of the UE > 30
26. Simulation time *s* has not reached
27. Create new users and add to *n*

Fig. 5. Pseudo algorithm

Since the worst case scenario of the proposed algorithm holistically handles these different UE speeds, as expected, a higher time complexity is recorded for this scenario. Therefore, in contrast to the existing algorithm, the proposed algorithm achieved an encompassing robustness by considering the different speeds of the UEs. Thus, the overall performance of the proposed algorithm in terms of reducing handover should be better from the result that will be obtained later in this work.

B. Traffic Analysis of the Femtocell Network

The UE's traffic behavior in the femtocell network for the proposed algorithm is analyzed as follows. By using the Discrete Time Markov Model (DTMM), the behavior of the UE in the network can be captured. The handover probabilities of the UE in each femtocell can be used to

obtain closed-form expressions for the handover performance parameters. Since the UEs can be placed anywhere in the network, they can also change the state at the end of a discrete time slot (Δt). State variables can be used to indicate an active UE call within the femtocell.

In the DTMM shown in Fig. 6, let N represents the number of the target femtocell in the network and the state variable $S(N)$ represents that the UE is associated with N. Let the additional state variable Sno represent the UE with no active call. As earlier stated, the calls are generated with arrival rate γ with the call arrival probability $P\gamma = \gamma\Delta t$. The call duration is exponentially distributed with the average call duration $1/\mu$. Therefore, the probability of the call termination is given as $P\mu = \mu\Delta t$.

The cell dwell time is the time that the UE spent in its current cell. It is given as $1/\eta$ and it is modeled using exponential distribution. The average cell residence time is given as 1/r and the probability of an UE leaving the current cell is $Pr = r\Delta t$.

The EU remains in an inactive state Sno with a probability of $1\text{-}P\gamma$. After the call arrival, the EU goes into any of the states Si with regards to the density of the cell in that state. The EU, thereafter, returns to the Sno from Si with a probability $P\mu$. The EU stays in the current cell during active call with a probability $(1\text{-}P\mu)(1\text{-}Pr)$ while the EU transition probability from Si to state Sj is given as $Pr(1\text{-}P\mu)Psisj$. The EU returns to state Sno at the end of a call.

The Ps_is_j can be calculated as follows:

$$Ps_is_j = \{¼ \text{ if } N > 3 \text{ or } 1 \text{ if } N = 3\} \tag{4}$$

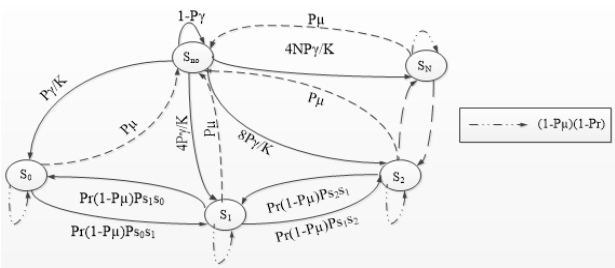

Fig. 6. DTMM for all states

where K is the total number of the femtocells in the network.

The balance equations can be determined using the transition probability matrix of the DTMM as follows:

$$\delta_{id} = (1 - P\gamma) + P\mu \sum_{i=0}^{k} \sum_{j=1}^{[\frac{i+1}{2}]} \tag{5}$$

where δ_{id} is a stationary distribution used to obtain the handover performance parameters.

The number of handover can be obtained by calculating the average handover number in the network. To calculate this, the handovers in each of the different call types have been considered. The average handover can be determined using the close-form expression as:

$$H_{avg} = \frac{1}{\ell}\left[\frac{\ell}{n}\right]\left\{h\phi + h\theta + \sum_{i=1}^{K}\sum_{j=1}^{\left[\frac{K+1}{2}\right]} h\phi\right\} + \frac{1}{\ell}\left(\ell - \left[\frac{\ell}{n}\right]\right)\left\{h\phi + h\theta + \sum_{i=1}^{K}\sum_{j=1}^{\left[\frac{K+1}{2}\right]} h\phi\right\} \tag{6}$$

where ℓ is the average number of handovers per UE. n is the number of handovers during an active call. h is the handover number to a femtocell/macrocell in state S. ϕ is the probability that a UE handover to a state which is not its current state. θ is the probability of the EU handover from one femtocell/macrocell to another whose is state S.

V. Performance Analysis and Results

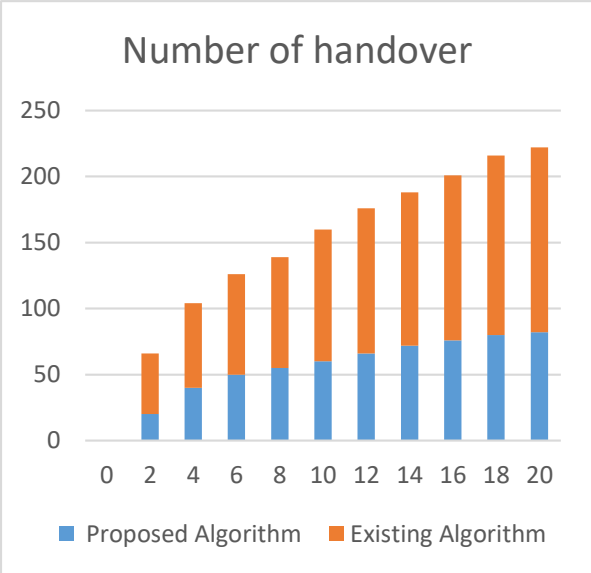

Fig. 7. Number of handover against new call arrival rate

The performance of the proposed algorithm is evaluated by comparison with the existing algorithm using the number of handovers and the ratio of the T-HeNB. Using the simulation parameters given in [17], the results of the proposed algorithm is presented with respect to the number of handovers as shown in Fig. 7. In this study, the algorithm with no mechanism to handle UEs speed is regarded as existing algorithm, (such as reference [20]). By comparing the results of the proposed algorithm with the existing algorithm, which allows the UE to handover to the femtocells without considering the speed of the UE, it can be noticed that there are more handovers in the existing algorithm. This can be attributed to the fact that when the UEs become mobile, they experience more handovers due to the low coverage area of the femtocells. This can lead to more packet loss, and a large load signalling in the core network. The frequent handover can be prevented by considering the speed of the UE in the proposed algorithm. Having determined the speed of the UE beforehand, the proposed scheme ensured that mobile UEs remained attached to the cell with wider coverage by initiating inter-frequency

handover to the macrocell while stationary or low speed UEs can handover to the femtocell. Although the proposed algorithm exhibits a higher computational time (as determined in the algorithm complexity for the worst case scenario) due to encompassing UE's speed consideration, however, as shown in Fig. 7, the proposed algorithm has been able to reduce the total number of handovers in the network by almost 40% of the existing algorithm.

The performance of the proposed algorithm can also be evaluated in terms of the ratio of the T-HeNB. The ratio of the T-HeNB is defined as the number of the target HeNBs in the list to the total number of the femtocells in the system.

$$T-HeNB(Ratio)=\frac{T-HeNBs}{Totalfemtocells} \tag{7}$$

The result of the ratio of the T-HeNB versus the number of the femtocell is shown in Fig. 8. In comparing the proposed algorithm with the existing algorithm, it can be noticed that the ratio of the T-HeNB in the existing algorithm doubled the ratio of the T-HeNB in the proposed algorithm for every increase in the number of the femtocell. This is because the mobile UE performed frequent handovers from one femtocell to another and because of the number of the femtocells, the rate of the ping-pong increases in the existing algorithm. However, with the proposed algorithm, only the stationary or low speed UEs can perform handover to the femtocell and the mobile UEs remain connected to the macrocell or handover to another macrocell thereby reducing the ping-pong effect.

The equation (6) is used to determine the number of handover. In Fig. 9, the total number of handovers in the system is small when few numbers of deployed femtocells are considered for both the analytical and the simulation models. However, as the number of deployed femtocell increases, there is an increase in the curve of the two models indicating that more handovers occurred when more femtocells are deployed even though they both tried to reduce the number of handovers. The two results do not vary significantly. When the deployed femtocell is around 500, the two curves meet and then closely follow each other for the rest of the curve. The idea here is not to compare the proposed models with the existing model as we have already compared the simulation model with the existing model. The aim is to see whether the results obtained analytically corroborate with the simulation results. Hence, it can be said that the results for both the analytical and the simulation models are closely related. The same close behavior can be noticed in Fig. 10 when both models are compared with respect to the ratio of the T-HeNBs. The ratio of the T-HeNBs increases for both models with no significant difference in the two. Thus, the accuracy of the proposed algorithm can be validated based on the closeness of the simulation and analytical models.

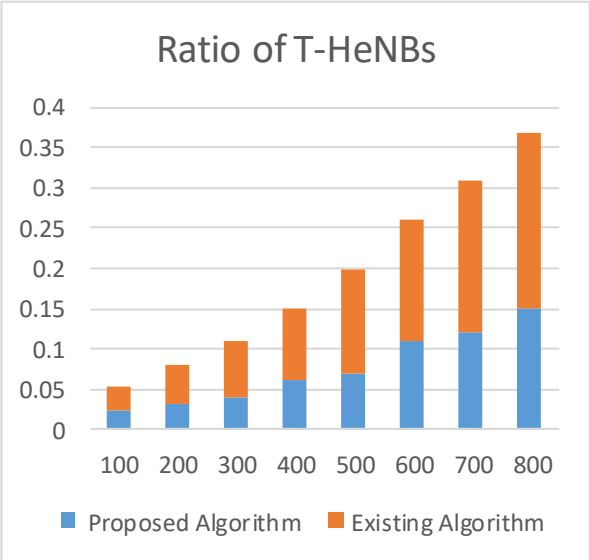

Fig. 8. Ratio of T-HeNBs

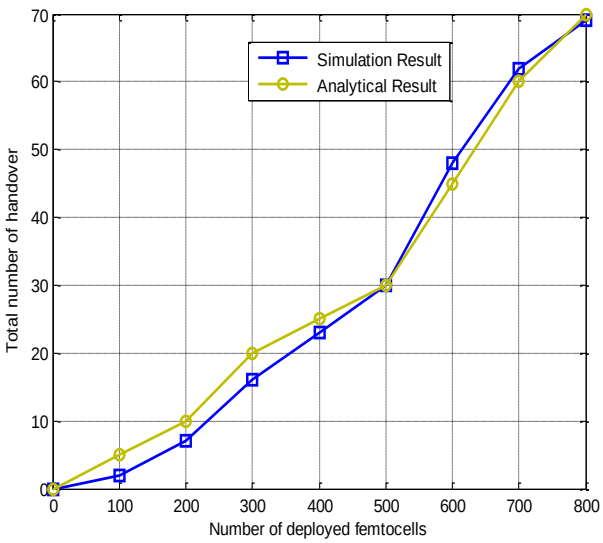

Fig. 9. Handover simulation result vs Analytical result

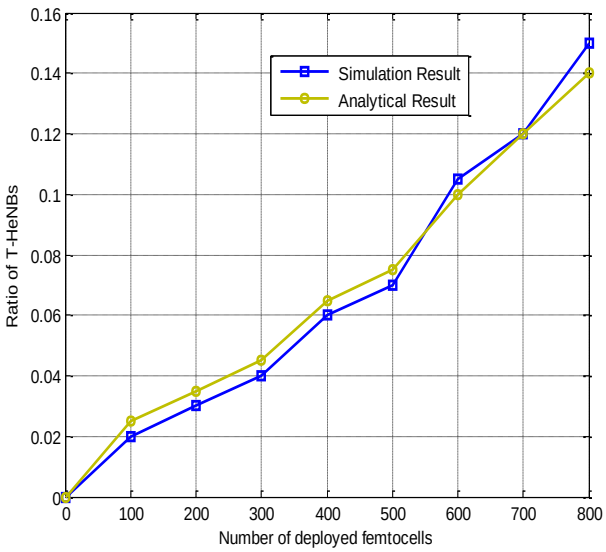

Fig. 10. T-HeNBs simulation result vs Analytical result

VI. Conclusion and Recommendation

In this work, challenges of femtocell were identified while an improved algorithm intended to reduce and enhance better performance analysis of handover has been presented. The proposed algorithm considered UE's mobility and signal level of other connected UEs. The performance of this algorithm, which was determined by comparing it with existing algorithm without consideration for the UE's mobility and signals of the other connected UEs, in terms of the number of handovers and the ratio of target femtocells is found to be better. Effect of the UE's mobility on the complexity of the algorithm has also been determined in this work.

In addition, the accuracy of the proposed algorithm is validated by comparing the simulated and analytical results together.

Future research can consider adjusting the power of femtocell access point and the macrocell dynamically to reduce unnecessary handover in LTE-Advanced or future networks.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Olusegun O. Omitola (OO) and Viranjay M. Srivastava (VMS) conducted this research analysis; OO designed this model after that analyzed the data and wrote the paper; VMS has verified the result of the designed model with consultation of OO; all authors had approved the final version.

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Dr. Olusegun O. Omitola received his M.Sc. in Mobile Computing and Communications from the University of Greenwich, London, United Kingdom in 2012 and B.Tech degree in Computer Engineering from Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Nigeria, in 2007. He is a lecturer at the department of Electrical, Electronic and Computer Engineering, Afe Babalola University, Nigeria. He is currently pursuing his PhD in Electronic Engineering at the University of KwaZulu-Natal, South Africa. He has published several papers in international refereed journals. His interests include mobile and wireless communications, femtocells, LTE/LTE-A and beyond, and mobile ad-hoc networks. Omitola is a registered engineer with Council for Registration of Engineering in Nigeria (COREN), and a student member of IEEE.

Prof. Viranjay M. Srivastava is a Doctorate (2012) in the field of RF Microelectronics and VLSI Design, Master (2008) in VLSI design, and Bachelor (2002) in Electronics and Instrumentation Engineering. He has worked for the fabrication of devices and development of circuit design. Presently, he is working in the Department of Electronic Engineering, Howard College, University of KwaZulu-Natal, Durban, South Africa. He has more than 17 years of teaching and research experience in the area of VLSI design, RFIC design, and Analog IC design. He has supervised various Bachelors, Masters and Doctorate theses. He is a Professional Engineer of ECSA, South Africa and Senior member of IEEE (USA) and IET (UK), and member of IEEE-HKN, IITPSA. He has worked as a reviewer for several Journals and Conferences both national and international. He is author/co-author of more than 200 scientific contributions including articles in international refereed Journals and Conferences and also author of following books, 1) VLSI Technology, 2) Characterization of C-V curves and Analysis, Using VEE Pro Software: After Fabrication of MOS Device, and 3) MOSFET Technologies for Double-Pole Four Throw Radio Frequency Switch, Springer International Publishing, Switzerland, October 2013.