



A Delay-Aware Approach for Energy Efficient Handover Procedure in Millimeter wave Heterogeneous Network

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ABSTRACT

This paper presents a delay-aware approach for energy efficient handover procedure in millimeter-Wave (mmWave) Heterogeneous Network (HetNet). In large open dense areas, high numbers of people use their smart phones to share pictures or data and download other information. This behavior creates traffic profiles that differ from those typically seen in the traditional network in less dense areas where less uplink traffic and less frequent packet transmission will be experienced. The mm-Wave HetNet deployment is a promising solution to address the spectrum shortage in 5G cellular systems. This is due to its large bandwidth available for meeting the increasing demand of mobile traffic. However, a major challenge for mm-Wave HetNet is to manage the user mobility and handovers in mm-Wave small cells. In addressing this problem, researchers are currently focused on applying several cell selections approaches in improving on the handover process for user's mobility. Despite a number of efforts made to mitigate this problem, network users still experience significant degradation in call quality owing to the dissimilarities in access technologies available and the user unpredictable movement patterns in both Line-of-Sight (LoS) and Non-Line-of-Sight (NLoS) paths. This paper proposes a handover decision algorithm, which is based on the user's changing speed, a normalized transmit power of the Base Stations (BS) and network connection time in order to make the handover decision better whilst guaranteeing improved system throughput. Results obtained using MATLAB R2020b version showed that the developed handover algorithm (EE-VHDA) reduced the number of handovers with respect to the number of Femto Base Stations (FBSs) by 52.83% and 8% when compared with the existing RBH and SMART algorithms respectively. Additionally, the developed algorithm obtained 2.74% and 5.64% improvement in system throughput with respect to the number of FBSs in comparison to the existing RBH and SMART algorithms respectively.

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INTRODUCTION

Massive deployment of small cells is seen to be a vital innovation in 5G, which enables frequent frequency reuse and higher data rates (Andrews et al., 2014). Small cells, however, present a major challenge for users moving at high speeds. This is because the smaller coverage

areas of small cells lead to frequent handover, resulting in lower throughput and longer delay (Andrews et al., 2014). Furthermore, 5G networks are characterized by extensive bandwidth at millimeter-Wave (mmWave) frequencies to offer high data rate services in cellular networks (Andrews et al., 2014). Although mmWave signals

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can provide extensive bandwidth, they are more sensitive to blockage effects than conventional lower band signals (Polese et al., 2017). Therefore, mmWave bands experience severe received signals attenuation due to blockages caused by buildings, trees, and even the user's hand or body. Overcoming the channel quality gap between Line-of-Sight (LoS) to Non-LoS (NLoS) conditions in mmWave bands still poses a major challenge in 5G networks since it can reduce the network capacity and user Quality-of-Experience (QoE) (Polese et al., 2017).

Moreover, with exponential growth and evolution of information and communication technology, energy consumption is also growing at a very fast rate (Polese et al., 2017). The energy consumption is growing even more with the deployment of 4G systems worldwide. Thus, there is the need to shift focus from pursuing high capacity and spectral efficiency to energy efficient designs (Polese et al., 2017). Researchers are of the opinion that, by minimizing power consumption of wireless networks, energy efficiency can be improved upon. The energy efficiency of 5G networks is expected to be increased 100 times in IMT-Advance and future (Andrews et al., 2014). Researchers are currently on-going on the next-generation wireless networks, including the Third Generation Partnership Project's (3GPP), Long Term Evolution-Advanced (LTE-A) and IEEE 802.16 standard with the focus on vertical handover techniques between the macrocell and the mobile small cells as a means to reduce the power consumption (Yang et al., 2009).

Energy saving schemes is usually utilized to facilitate the user with desired quality of services for a long time. When the user moves in overlapping area of different wireless networks, vertical handover techniques are used for optimum network selection (McNair et al., 2004). The process of vertical handover is accomplished in three phases, including initiation, decision making, and execution. Even though each phase is important, handover decision still remains the vital among these and it involves lot of network related measurements such as relative signal strength, cost, security, delay, packet loss,

reference signal received power, etc (Baghla et al., 2017).

5G Mobile Cellular Networks

A cellular network is a radio network whose cells are distributed over geographical areas. Each cell is served by a fixed location transceiver known as a base station. Cellular networks run on technology platforms which evolved from the First Generation (1G) to the current 4G LTE mobile cellular network. The 5G wireless network is yet to be standardized and is currently being developed to provide better performance as compared to the 4G mobile cellular networks. The four performance requirements for 5G mobile networks are (Bogale et al., 2016):

1. A minimum user-experience data rate of 1 Gbps.
2. Round-trip latency of about 1ms.
3. Connected devices up to 100 times that of the present 4G mobile cellular network.
4. Energy efficiency of 10 times that of the current 4G mobile cellular network.

The performance requirements which have been accepted by the wireless industry and academia as the main driving force for the 5G mobile cellular network development are explained by three elements as follows:

Data Rate: It is undeniable that the data rate plays the most significant role in the design of 5G cellular networks since mobile traffic explosion is the main driving force behind 5G technology. The data rate can be measured in terms of aggregate data rate, edge data rate, and peak data rate (Andrews et al., 2014):

1. Aggregate data rate is defined as the total amount of data the network can support, characterized in bits/sec per unit area.
2. Edge data rate represents the worst data rate a UE experience within the range of the network. The 5G edge data rate is 1 Gbps.

3. Peak rate is the best data rate of a UE under any conceivable network configuration and it is in the range of tens of Gbps.

Latency: The latency of a mobile network is the time required to deliver data from the source to the destination (Bogale et al., 2016). The latency of 4G can meet the requirements of most current applications. This is driven by the emerging new applications, but the anticipated round-trip latency for 5G cellular networks is about 1 ms (Andrews et al., 2014).

Energy and Cost Efficiency: 5G wireless networks is designed to achieve better cost efficiency to solve the issue of mobile operators' interest about revenue flattening, and most crucially, the energy efficiency of the 5G wireless network is to be improved by a factor of 10 compared with the 4G wireless network (Le et al., 2015).

Enabling Technologies of 5G

Significant improvement in the aggregate data rate can be achieved through the combined gains in these three categories (Andrews et al., 2014):

1. Heterogeneous dense deployment with the small cell to increase the number of base stations in the area.
2. Moving toward and into mmWave spectrum to obtain a huge and clean system bandwidth.
3. Taking advantages of advances in MIMO (such as massive MIMO) to increase spectral efficiency (support more bits/sec/Hz per BS).

Enabling Technologies of 5G

Radio resource management refers to the processes, strategies and algorithms for monitoring parameters such as transmission energy, user allocation, data rates, handover criteria, modulation scheme, and error coding scheme to make the most effective use of radio resources (Mamane et al., 2019).

The three main roles of RRM are:

1. Power transmission management.
2. Preventive and reactive congestion control.
3. Radio resources allocation.

Handover Decision Mechanisms

Handover decision mechanism can be found in the network domain or in the mobile terminal and this is dependent on the measurement of certain parameters involved. Based on this, handover are classified into four scenarios (Zekri et al., 2012) as follows:

1. Network Controlled Handover (NCHO): In this type of handover, the network is in control of the handover decision process.
2. Mobile Controlled Handover (MCHO): In MCHO mechanism, the UE takes its own measurement while also making handover decision.
3. Mobile Assisted Handover (MAHO): Here, the measurement and information from the UE are utilized by the network to decide the handover.
4. Network Assisted Handover (NAHO): In NAHO, the network retrieves information that is useful to the UE in a handover decision.

Densification of Macrocell with Small Cells

A heterogeneous 5G network incorporates two different kinds of cells namely macrocells and small cells. The primary operation of heterogeneous networks is that numerous smaller cells operate under the umbrella of macrocells to increase the coverage, promote frequency reuse, and enhance the ability to support high traffic rates for all areas (EISawy et al., 2013). Small cells are classified into microcells, picocells, and femtocells. The important features of macrocell and the three small cells for heterogeneous networks are as follows (Andrews et al., 2014):

1. Macrocell: The cell diameter for a macrocell may range from 1 km (about) within the city to more than 40 km within a non-urban environment. With respect to the transmission power of the

- antennas, the value also is set by 46dBm (Zhu et al., 2016). Moreover, the radius of the macrocell is dependent on the following factors (Zhu et al., 2016):
2. Microcell: Compared to the macrocell, a microcell is smaller and possesses considerable differences in terms of requiring a smaller antenna with reduced power and power settings for transmission. These cells typically provide coverage up to 500m (Zhu et al., 2016).
 3. Picocell: A picocell serves as a wireless base station that is designed with very

low power output for coverage of a very small area, like a single floor of an office building (Zhu et al., 2016). The cellular network of picocells tends to provide coverage extensions for indoor areas that face weakened received of the signals.

4. Femtocell: Femtocells are smaller in the coverage size and the transmit power compared to picocells, microcells, and macrocells. Femtocells can be used in a home or small office buildings. The transmit power of femtocells is often less than 100 mw (Zhu et al., 2016).

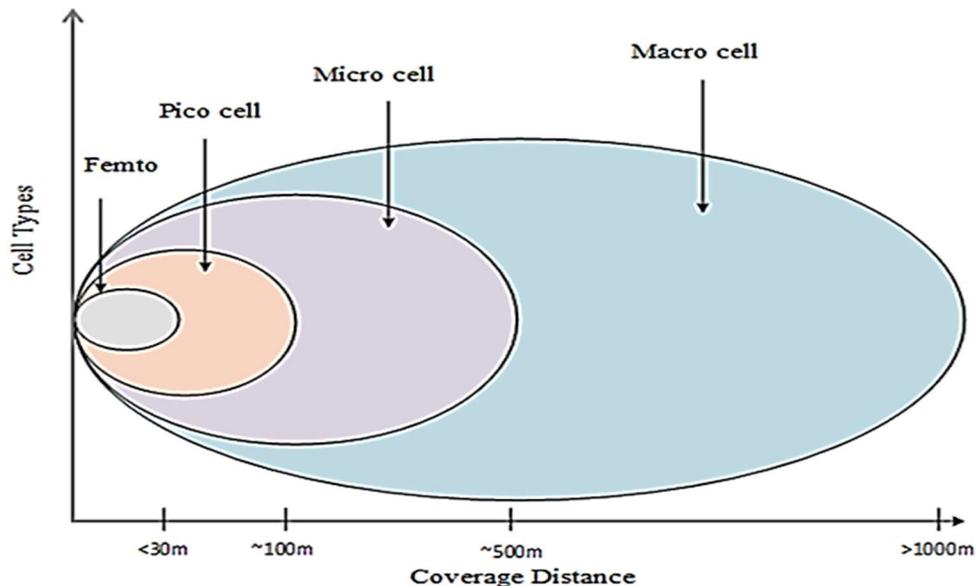


Figure 1: Deployment of Small Cells in a Macrocell (Patel et al., 2010).

REVIEW OF RELATED WORK

Xenakis et al. (2016) proposed a novel handover decision algorithm which utilized measurement from candidate cells to optimize two Handover Hysteresis Margins (HHMs). The first HHM was used to avoid cells that could compromise service continuity, while the second HHM was used to identify the cell with the minimum required UE transmit power. The cell that required the minimum UE transmit power was subsequently selected and the handover execution phase was initiated. However, in using the candidate cell list as an input to the algorithm,

there were delays associated with the handover decision since the list was not optimized; as this would adversely affect the performance of the results obtained. (Khan et al., 2017) examined a handover algorithm for hand-in procedure. In the work, a multi-step handover scheme was used for the purpose of reducing the number of unnecessary handovers, while also selecting the appropriate Femto Access Point (FAP) for the incoming UE. The proposed handover algorithm showed better performance than already existing hand-in algorithms. However, the work did not consider the delays that could arise from having to check, select and measure for the available and

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target femtocell. This would deplete the energy resources of the network, thereby resulting to a degradation of the UE's QoS.

Alhabo et al. (2017) designed a handover decision algorithm that makes use of the actual distance between the User Equipment (UE) and the Small Cells (SCs) and the UE angle of movement, for the purpose of creating a shortened candidate list which assisted in minimizing the energy resource that would have been dissipated in the process of scanning for the candidate cells thereby reducing the number of unnecessary Handovers (HOs) while increasing the network throughput of the system (Aliu & Momoh 2021). However, the delay that could eventually arise from the scanning process could affect the performance of the HO process, especially in a scenario where the UE moves at varying speeds. Furthermore, no prediction scheme was utilized to effectively describe the user's movement towards the target cell, as this could have improved the results obtained.

Sun et al. (2027) presented a SMART handoff policy for mmWave HetNet based on reinforcement learning. In SMART, the handoff trigger conditions were derived by taking into accounts both mm Wave channel characteristics and QoS requirements of UEs. Numerical results showed that the performance of SMART was close to the optimal solution without disrupting the UE QoS. However, the delay that would arise from the selection algorithm could adversely affect the timely execution of the handover decision process, thereby leading to a degradation of the QoS of the users.

Arshad et al. (2017) analyzed a velocity-aware handover management scheme for two-tier downlink cellular network to mitigate the handover effect on the foreseen densification throughput gains. In the work, the proposed handover scheme sacrificed the best base station (BS) connectivity, by skipping handover to some BSs along the user trajectory, to maintain longer connection durations and reduce HO rates. The results obtained showed an improvement of 77% rate gains, which could be harvested through the proposed handover scheme when compared to the conventional handover scheme that usually

maintained the best RSS association. However, by skipping the best base station connection, the UE QoS would be compromised, thereby leading to a degradation of the QoE of the user (Adedokun et al., 2019). Also, Tahir et al., (2018) developed a novel 5G wireless network architecture that comprised of two main aspects of massive MIMO-OFDMA and IP based vertical handover.

The proposed architecture divided the whole macro area network into microcells and each micro-cell consisted of multiple small cells. All the cells were manipulated by their adjacent massive MIMO-OFDMA base stations. Simulation results showed an improvement in the network performance in terms of energy efficiency when compared to conventional vertical handover schemes. However, the effects of energy requirements for both the static and dynamic components of the base stations were not considered, as this would have further improved the results obtained in terms of energy efficiency. (Kishida et al., 2018) proposed a cell selection scheme for handover reduction based on moving direction and velocity of UEs for 5G multi-layered radio access networks (RANs) architecture. The authors designed a cell selection scheme that took into account the direction of movement of the sets of user equipment (UE) and the location of candidate cells for connection.

The simulation results showed that the proposed scheme required 30% fewer handovers without any degradation in the average end-to-end transmission time when compared to the conventional power detection-based scheme. The pitfall of the work was that, the effect of energy efficiency at the base stations was not considered, as this would further improve on the results obtained. Kishida et al. (2018) presented an energy efficient vertical handover technique for heterogeneous networks. In the work, an energy efficient vertical handover technique was suggested and analyzed for different traffic classes. The proposed approach was based on vector normalized preferred performance based VIKOR algorithm (V-VPP) for performing handover. The proposed scheme resulted in a decrease in number of handovers as well as optimum network selection. Despite the

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commendable results of the work, the authors did not take into consideration the effect an appropriate cell residency time would have on the proposed handover scheme; as this would have improved on the results obtained.

Baghla et al. (2018) proposed an offline scheme based on Double Deep Reinforcement Learning (DDRL) to minimize the frequency of Handovers (HOs) in mm-wave networks, which subsequently reduced the adverse QoS of the users. In the work, the authors deployed the DDRL algorithm with offline learning framework, such that historical user trajectory information was leveraged in order to develop a policy that guaranteed the selection of the optimal BS during HOs by considering both the number of HOs and system throughput. Numerical results showed that the designed DDRL algorithm significantly outperformed both the conventional and existing artificial intelligent-based HO policy in terms of handover occurrence and throughput. However, the authors did not consider the effect of the changing speed of the users, as this would have significantly improved the results obtained. Summarily, with the incorporation of a cell residence timer, normalization of the unequal transmits powers of both the macro and small cell BSs, its effect would result in an improved performance in terms of a reduction in the number of handovers whilst achieving higher system throughput.

EE-VHDA (DEVELOPED HANDOVER ALGORITHM)

To address the issues of handover and system throughput with respect to FBSs, a handover scheme that takes into cognizance the changing speed of the user, the transmit powers of the cell base stations and a cell residence time is presented. The following steps were used in the development of the EE-VHDA.

1. For simulation purpose, a macrocell-femtocell network architecture made up of one macrocell and multiple femtocells was used.
2. Non-random movement mobility model to model the movement pattern of the UE with respect to LoS paths at constant speed was obtained.
3. Random movement mobility model to model the movement pattern of the UE with respect to NLoS paths at varying speed was obtained.
4. The path loss model adopted for mmWave cell users is given (Mollel et al., 2020) as:

$$L(d) = \alpha + 10\eta \log_{10}(d) + \xi|dB|, \xi \sim N(0, \theta^2) \quad (1)$$

where:

d is the distance in meters,

α and η are the least square fits of floating intercept and slope over the measured distances (30 to 200 m)

θ^2 denote the lognormal shadowing variance

In this paper, it is assumed that the total number of handovers performed during the handover decision phase is expressed mathematically (Alhabo et al., 2017) as:

$$HO_{total} = NHO_m + NHO_{s \rightarrow s} \quad (2)$$

SYSTEM MODEL

The system model as shown in equation (3) defines the UE movement pattern in both LoS and NLoS paths. This research work adopted the experimental value of 200m as its radius which is based on the equivalent LoS ball model (Singh et al., 2015).

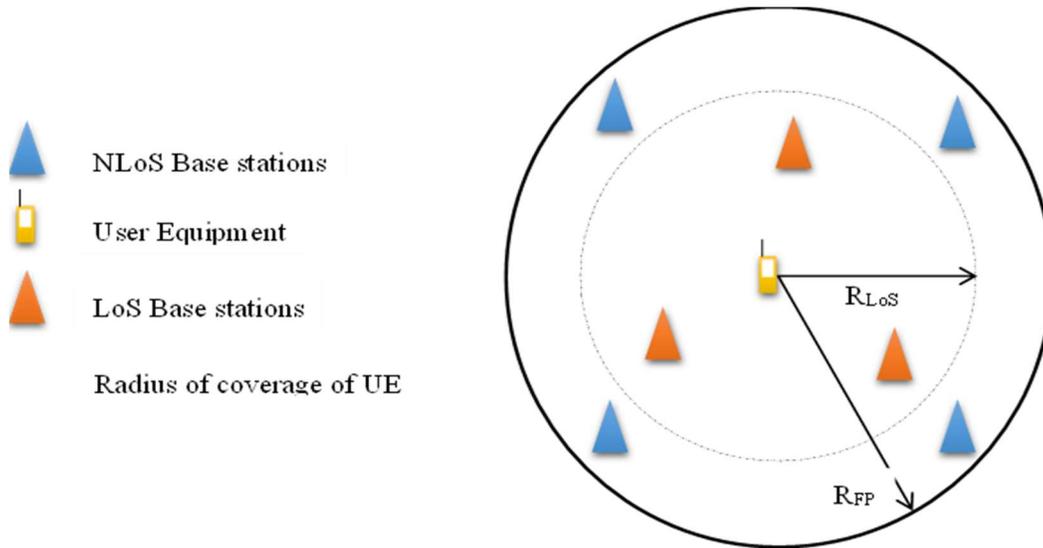


Figure 2: Proposed LoS and NLoS Paths Network Model

Based on assumption, the mathematical conditions that satisfies LoS and NLoS paths for the developed system model is given as:

$$CA_{r(t)} = \begin{cases} r \leq R_{LoS} & \text{for LoS} \\ R_{LoS} < r \leq R_{fp} & \text{for NLoS} \end{cases} \quad (3)$$

where;

$CA_{r(t)}$ represent the coverage area indicator for LoS and NLoS.

r denote the radius of coverage of UE

R_{fp} define the total coverage area condition for both LoS and NLoS

$r(t)$ refer to the residence time for which the UE should spend on either the macrocell or small cell as it moves through the LoS and NLoS paths and is defined as:

$$r(t) = \frac{S}{D_{ms}} \quad (4)$$

Where S represent the current speed of the UE

and D_{ms} denote the distance of the UE from either the macro cell or small cell on the LoS and NLoS paths.

From equation (5), if $r \leq R_{LoS}$, it means that the pathloss model in use is LoS. Also, if

$R_{LoS} < r \leq R_{fp}$ condition occurs, it implies that the pathloss model for NLoS is been implemented.

The system model in Figure 2 is a one-cell network. The base stations are randomly distributed in a Poisson point process (this is to maintain tractability of the user movement in both LoS and NLoS scenarios). The dotted lines as indicated in Figure 2 represent the radius of the UE within the LoS path, while the thick circle is the coverage size of the cell network as well as the coverage area for the macrocell network. The triangle in red depicts base stations within the radius of the LoS (R_{LoS}), while the triangle in blue denotes the base stations at the radius of the footprint (R_{fp}) as well as the NLoS base stations. The UE position as it moves through the LoS or an NLoS path is determined by the 3GPP standard pathloss models for both LoS and NLoS. The UE moves at different speeds within the cell structure. As the UE moves at varying speeds through the LoS and NLoS paths, handover process takes place. When the UE speed goes above the 120 km/hr. (Bai et al., 2014) threshold, the UE performs handover to the macrocell. When the UE speed becomes less than or equal to 120 km/hr. the UE performs handover to any of the candidate small cells.

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Estimating the Handover Triggering Process for Macro-Cell and Small-Cell Users with Respect to the LoS and NLoS Conditions

In mmWave heterogeneous networks, the Reference Signal Received Power (RSRP) from macrocell and small cell base stations are modeled as the output powers of Macro cell BS and Small cell BS minus the pathloss of macro cell and small cell signals, respectively. This is described (Itoh et al., 2002) as:

$$P_m = T_m - TL_m \quad (5)$$

$$P_s = T_s - TL_s \quad (6)$$

where;

P_m and P_s denote the RSRP from MBS and SBS, respectively

T_m and T_s represent the fixed output powers of MBS and SBS,

TL_m and TL_s refer to the pathloss for macrocell and small cell signals, respectively.

However, the pathloss models of macrocell and small cell signals are expressed (Itoh et al., 2002) as:

$$TL_m = TL_{0m} + \eta_m 10 \log \left(\frac{l_m}{l_{0m}} \right) + TL_{sm} \quad (7)$$

$$TL_s = TL_{0s} + \eta_s 10 \log \left(\frac{l_s}{l_{0s}} \right) + TL_{ss} \quad (8)$$

where;

TL_{0m} and TL_{0s} define the pathloss of the macrocell and small signal at reference distances, l_{0m} and l_{0s} respectively.

l_m and l_s are the logarithmic scaling with the distance from the mobile station to the macro and small BSs,

η_m and η_s represent the pathloss exponents for macro and small BSs,

TL_{sm} and TL_{ss} comprise the log-normal shadowing for macrocell and small cell signals

Thus, the UE moving from x_i to x_j has the shadowing correlation coefficient $C(x_i, x_j)$ described as (Itoh et al., 2002):

$$C(x_i, x_j) = bl_{ij} = \sigma^2 e^{-\frac{l_{ij}}{D_c}} \quad (9)$$

Where;

$$l_{ij} = |x_i - x_j| \quad (10)$$

bl_{ij} denote the correlation coefficient
 σ is the standard deviation of the Gaussian random variables, and

D_c refer to the effective correlation distance

However, this paper assumed that the probability of signal degradation $\Pr[SDG]$ during the handover triggering phase be defined as the probability of occurrence of the event that the delay (d) at the serving BS exceeds the delay threshold T_d or the reference signal received power T_p falls below. Hence, the probability is formulated as thus:

$$\Pr[SDG] = \Pr[(d > T_d) \cup (P < T_p)] \quad (11)$$

$$= 1 - \Pr[d \leq T_d] \Pr[P \geq T_p] \quad (12)$$

Where;

d represent the probability of the occurrence of delay at the serving BS

Based on equation (12), two different cases are considered

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CASE ONE

If the serving cell is a macrocell BS,

$\Pr[SDG_m]$ is defined as:

$$\Pr[SDG_m] = 1 - \Pr[d_m \leq T_d]$$

$$\Pr[P_m \geq T_p] \quad (13)$$

where; d_m is the probability of occurrence of delay at the macro-BS and P_m denote the Reference Signal Received power of the macro BS ($RSRP_m$).

Equation (13) is simplified as:

$$\Pr[SDG_m] = \Pr[RSRP_m < T_p] \quad (14)$$

By Substituting equation (5) into equation (14) gives:

$$\Pr[SDG_m] = \Pr[T_m - TL_m < T_p] \quad (15)$$

However, combining the pathloss of macrocell signal (TL_m) defined in equation (7) with equation (15) gives:

$$\Pr[SDG_m] = \Pr[T_m - TL_{0m} - \eta_m 10 \log\left(\frac{l_m}{l_{0m}}\right) - TL_{sm} < T_p] \quad (16)$$

CASE TWO

If the serving cell is a small cell BS, by applying equation (12) $\Pr[SDG_s]$ is described as:

$$\Pr[SDG_s] = 1 - \Pr[d_s \leq T_d] \Pr[P_s \geq T_p] \quad (17)$$

By combining the RSRP of the small cell (P_s) defined in equation (6) with equation (17),

$\Pr[SDG_m]$ is then expressed as:

$$\Pr[SDG_s] = 1 - \Pr[d_s \leq T_d]$$

$$\Pr[T_s - TL_s \geq T_p] \quad (18)$$

Imputing the pathloss of small cell signal (TL_s) defined in equation (8) into equation (18) gives:

$$\Pr[SDG_s] = \Pr\left[T_s - TL_{0s} - \eta_s 10 \log\left(\frac{l_s}{l_{0s}}\right) - TL_{ss} \geq T_p\right] \quad (19)$$

Since there exists a difference between the transmit powers of the macro cell and the small cell, the Received Power from the candidate small cells ($RSRP_{sc}$) and the Received Power from the macro cell ($RSRP_m$) cannot be compared directly. The equivalent RSRP would be calculated when RSRP of small cell and RSRP of macro cell are compared. The proposed algorithm is based upon equivalent RSRP of small cell, denoted as $RSRP_{sce}$. The $RSRP_{sce}$ would make the received signal strength from the two cells comparable. The $RSRP_{sce}$ is computed mathematically as:

$$RSRP_{sce} = RSRP_{sc} + \left(\frac{NT_p}{d}\right) * RSRP_m \quad (20)$$

where d is the distance between the base stations, and it is to ensure that if the candidate small cell is located in the boundary region of macrocell, the UE would stand a higher probability of being connected to any of the small cells as it moves through the LoS and NLoS paths. The farther the small cell base station is from the macro cell base station, the more the value of the $RSRP_{sce}$. This strategy helps to ensure the robustness of the proposed algorithm, as a very weak signal received from the macro cell BS at the boundary, results to increased handover frequency.

SIMULATION ENVIRONMENT

MATLAB R2020b version was used in the simulation of this work. MATLAB R2020b was used to compare the performance of the EE-VHDA with the Existing SMART and RBH Algorithms. However, the Rate-Based Handover



(RBH) policy has similar trigger conditions as those in 3GPP. The simulation parameters used

in this work are as shown in Table 1. Figure 3 shows the flowchart of the EE-VHDA.

Table 1: Simulation Parameters.

Parameter	Value
Simulator	MATLAB 2020b
φ_{\max}	18db
φ_{\min}	2db
Carrier Frequency	2000MHz
MBS radius	500m
Power of MBS	46dBm
Power of mm-FBSs	30dBm
Power of FBSs	20dBm
Bandwidth of MBS/FBS	20MHz
Bandwidth of mm-FBS	500MHz

RESULTS AND DISCUSSION

Figures 4 and 5 shows the results of the performance of the RBH, SMART and EE-VHDA. The various results obtained through simulations are highlighted and discussed. Simulations were carried out for number of handovers against number of FBSs, and system throughput against number of FBSs respectively. The performance of the developed handover algorithm and the existing handover algorithms was analysed. The percentage improvement of the developed scheme over the existing RBH and SMART algorithms are presented in equations (21) and (22) respectively. A Markovian model for random motion was used for the network simulation. From

the plot, it can be observed that the developed handover scheme displayed a smaller number of handover and better system throughput when compared to the existing RBH and SMART handover schemes respectively.

$$\frac{\text{Percentage Improvement}}{\text{Existing RBH}} = \frac{EE-VHDA-Exis RBH}{\text{Existing RBH}} \times 100 \quad (21)$$

$$\frac{\text{Percentage Improvement}}{\text{Existing SMART}} = \frac{EE-VHDA-Exis SMART}{\text{Existing SMART}} \times 100 \quad (22)$$

Table 2a. System Throughput Improvement at varying Number of Femto Base Stations (FBs).

Performance Metric	Existing Scheme (Xenakis et al., 2014)	RBH EE-VHDA Scheme	Percentage Improvement
System Throughput	2.55	2.62	2.74%

Table 2b. System Throughput Improvement at varying Number of Femto Base Stations (FBs).

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Performance Metric	Existing Scheme (Xenakis <i>et al.</i> , 2014)	RBH	EE-VHDA Scheme	Percentage Improvement
System Throughput	2.48		2.62	5.64%

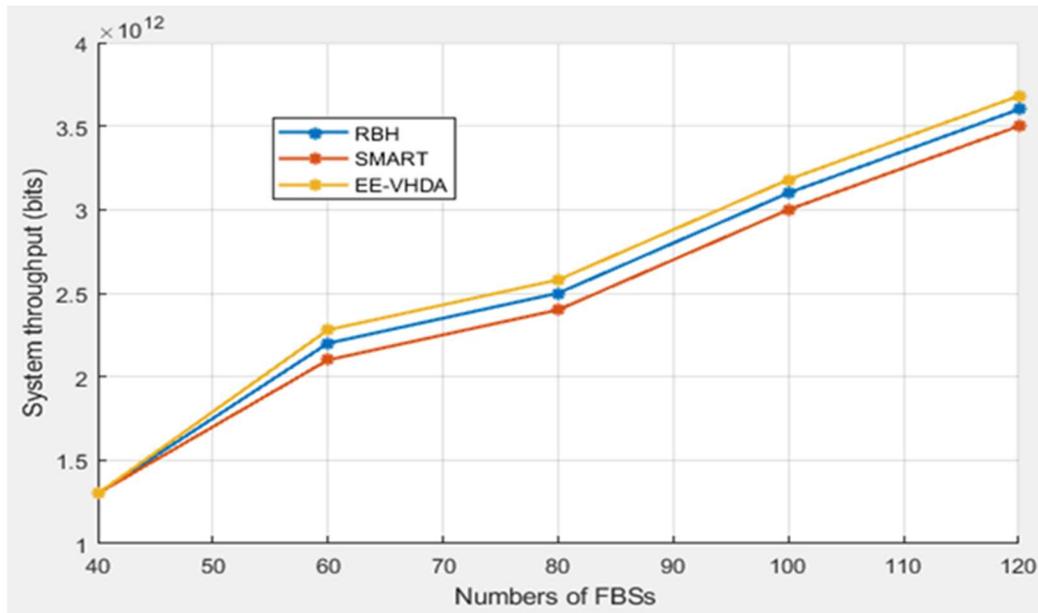


Figure 4: System Throughput at varying number of FBSs

Figure 4 illustrates the system throughput against the number of femto base stations during simulation. It is seen that as the number of FBSs increased, the system throughput for the RBH, SMART, and EE-VHDA also increased. This is justified by higher available wireless resources. As further observed in Figure 4, the RBH algorithm has better system throughput in comparison to the SMART algorithm as the number of FBs increased. This is so because, in the design of the RBH scheme, the UE prioritizes achieving maximum data rates

whilst performing handover frequently, hence ignoring the negative effect of the frequency in handover. However, the EE-VHDA obtained higher system throughput in comparison to both RBH and SMART algorithms. This is achieved by keeping track of the UE movement pattern through estimating the coverage radius of all the FBs within the specific LoS and NLoS paths of the UE. Figure 4 indicates that the developed EE-VHDA obtained a 2.74% and 5.64% improvement when compared to RBH and SMART algorithms.

Table 3a. Handover Percentage improvement for Femto Base Stations.

Performance Metric	Existing Scheme (Xenakis <i>et al.</i> , 2014)	RBH	EE-VHDA Scheme	Percentage Improvement
Number of Handover	8.533		4.025	52.83%

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Table 3b. Handover Percentage improvement for Femto Base Stations.

Performance Metric	Existing Scheme (Xenakis et al., 2014)	RBH	EE-VHDA Scheme	Percentage Improvement
Number of Handover	4.375		4.025	8%

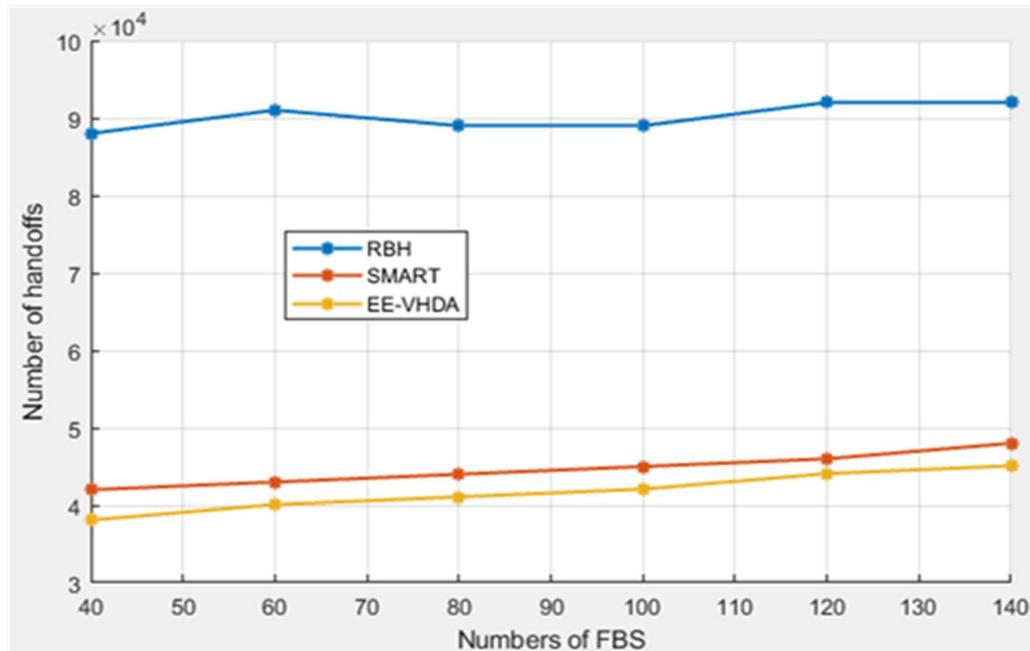


Figure 5: Number of Handovers at varying number of FBSs

Figure 5 presents the number of handovers against the number of femtocell base stations for RBH, SMART, and EE-VHDA schemes respectively. From the graphical description of the results on display in Figure 5, it is observed that there is a marked increase in the number of handovers as the number of femtocell base stations increased for all three handover models.

This is so because, as the femto base station deployment increases, there is a corresponding frequency at which handover would occur especially as the UE moves along both LoS and NLoS paths. Furthermore, a reduction in the number of handovers for the developed model when compared with the SMART algorithm as demonstrated in Figure 5 was achieved by the incorporation of a cell residence time to mitigate frequency in handover during the handover

decision process. Moreover, the marked improvement in the EE-VHDA scheme in comparison with the RBH algorithm is attributed to the handover process been simulated at non-mmWave frequency. These values obtained from Figure 5 showed that the developed EE-VHDA reduced handover by (52.83%) and (8%) when compared with RBH and SMART algorithms, respectively.

CONCLUSIONS

From the discussed results, it can be seen that the developed handover decision algorithm successfully improved the performance of the existing handover decision algorithms. The EE-VHDA reduced the number of handovers for FBs by 8% and 52.83% when compared with the SMART and RBH algorithms respectively. Additionally, the EE-VHDA obtained 2.74% and 5.64% improvement with respect to the number of

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FBSs in comparison to the existing RBH and SMART algorithms respectively. This reduction in the number of handover and improvement in system throughput were as a result of incorporating a cell residence time and normalizing the unequal transmit powers of the cells, hence enhancing the overall handover process. Furthermore, a reduction in number of handover and a better throughput entails an energy efficient handover scheme.

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