# Design and Evaluation of a Time Efficient Vertical Handoff Algorithm between LTE-A and IEEE 802.11ad Wireless Networks

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***Abstract*—By moving through the 5th generation (5G) of wireless communications, great enhancements and progress are visible in the wireless network protocols and their management methods. LTE-A and IEEE 802.11ad are two of the networks that can have complementary roles in 5G networking. This paper proposes a time efficient, predictive, and dynamic handoff algorithm between these two protocols. The algorithm presented measures the Signal to Interference Plus Noise Ratio (SINR), the Reference Signal Received Quality (RSRQ), velocity, and the Time of Stay (ToS) for pedestrian mobile users and calculates the best Time to Trigger (TTT) value accordingly. At the next step, obtainable throughput from target antenna and user's Quality-of-Service (QoS) requirements are considered as another decision parameter. One of the main advances of this algorithm is that the TTT value is calculated dynamically regarding user's velocity and Handoff Failure Ratio (HoFR). The algorithm presented estimates the user's next location and velocity using a Gauss-Markov mobility model and the Location Positioning Protocol (LPP) of LTE-A. Comparisons with other algorithms in this area determine that the algorithm proposed gains the least HoFR for these two protocols by avoiding unnecessary handoffs.**

***Keywords*—*Handoff, LTE-A, 802.11ad, Seamless Connection, Heterogeneous Networks, Offloading.***

## I. Introduction

Human interaction with communication systems has been rapidly increasing especially since wireless technologies have been integrated into cell phones. By heading towards 2020, it has been estimated that daily transacted data traffic in the Internet is going to increase to 1000 times of what was used in 2014. Next generation of wireless technologies (*i.e.*, 5G) follows a perspective in which the World Wide Wireless Web (WWWW) is introduced with the goal of providing limitless wireless connectivity for users with much higher speed than previous generations. Looking at the User Equipment (UE), it needs to support higher data rates as well as the wireless network Access Points (AP) [22].

UE corresponds to the endpoints of wireless networks by which users experience networks quality and utilize the infrastructures in the background. Regardless of the network type, *e.g.*, a Wireless Local Area Network (WLAN) or cellular networks, network management in 5G needs to provide seamless connections to users. UE is expected to support multiple generations (i.e., 3G, 4G, 5G) of wireless communications as well as different WLAN protocols (*e.g.*, IEEE 802.11 g and n) to provide seamless connectivity in different areas.

Two of the technologies which most probably will be used broadly in 5G are Long Term Evolution-Advanced (LTE-A) and IEEE 802.11ad (known as WiGig) [6]. LTE or Evolved Universal Terrestrial Access Network (EUTRAN) was first introduced in 2008 by the 3rd Generation Partnership Project (3GPP) which defines a certain type of union of the 8 telecommunication standardization organizations [1]. LTE was designed with the goal of improving previous technologies such as Global System for Mobile Communications (GSM) and General Packet Radio Service (GPRS) by providing high spectral efficiency, increase the data rates and bandwidth, reduce the Round Trip Time (RTT), and showes flexibility in frequency and bandwidth allocations [2].

From the Release 10 (R10) of LTE, 3GPP introduced its new technology LTE-A (LTE-Advanced). To reach compatibility of LTE-A with older versions of LTE, LTE-A supports Time Division Duplex (TDD) and Frequency Division Duplex (FDD). After LTE-A R10 other releases started by 3GPP and specifications of R11, 12, 13, and 14 are frozen at the moment and newer releases of R15 and 16 are still in progress [2], [7]. In this paper LTE-A R12 is referred to as LTE-A and is used for the simulation scenario as the one ready to implement specifications of 3GPP.

One of the major research areas in 5G is the offloading process. With offloading, user traffic traverses the local wireless AP instead of utilizing a continuous connection to cellular networks even in indoor areas. In case of using LTE-A in 5G, a proper network for offloading LTE-A communications with up and downlink data rates of higher than 1 Gbps needs to support the same data rates, otherwise, users will not be willing to switch to the local networks. One of the wireless technologies to support high data rates and being deployed in indoor areas as a replacement of traditional WiFi networks is the IEEE 802.11ad standard. This protocol is known as WiGig because of the Gigabit scale data rates it supports. WiGig provides almost 7 Gbps for downlink and almost 3 Gbps for uplink [18].

Switching the user's network from a home (already connected) network, to a new target network (one of the possible networks to be switched to) and vice versa is known as Handoff (HO) or Handover. The HO process must be followed to provide a seamless offloading. This process needs to be done smoothly, without data loss, and within the least possible amount of time in a way users do not notice this change. Since the first generations of wireless networks, many HO algorithms had been designed to provide seamless connections between various heterogeneous networks (cf. Section II for details).

In this paper, a new time-efficient HO algorithm is designed to provide specifically a seamless connection and offloading between LTE-A and WiGig networks as two of the networks might be used broadly in 5G for high data rates . Results of a comparison with other HO algorithms reveal (cf. Section IV) that the algorithm proposed is capable of reducing Handoff Failure Rates (HoFR) in a predictive fashion. Also, the Time to Trigger (TTT) is updated frequently based on measures defined, and the HO process follows a cross-layer algorithm to increase the time efficiency.

This paper is organized as follows: Section II presents related work. Section III explains major details of the algorithm proposed, including assumptions, message flows, and the HO decision phase. Specifically, parameters used in the decision-making phase of the new HO algorithm and their calculations are presented in the Section IV. Section V discusses the result of simulations and compares them to other algorithms' performance. Conclusions are drawn in Section VI.

## II. Related Work

HO algorithms are mainly divided into three phases. The first phase is "Initiation" in which the UE gathers network information such as received signal power. In the second phase, which is called "Decision Making", based on information gathered in the initiation phase, HO algorithms decide to start the HO and switch to the new network. The final phase is the "Termination" phase, where the UE cuts their connection from an old network and starts to operate in a new network. Among these three phases, the "Decision Making" phase determines the primary focus and action of the HO algorithms.

HO algorithms which are designed and proposed for heterogeneous networks are called "vertical" HO algorithm. Many vertical HO algorithms proposed for decision-making phase of HO process and in this section, some of the most relevant ones are going to be explained briefly.

The first HO algorithm is from [3], where two methods are chosen. In the first method, a utility function used to estimate the time a Mobile Node (MN) will stay in the base network after the HO process starts and before connecting to the target network. Based on the estimated value, proper TTT is calculated. In the second method, a fuzzy logic approach is proposed with the decision factors of Signal to Noise Ratio (SNR), Bandwidth (BW), Time of Stay (ToS) in Home Zone (HZ) and user's Velocity (V).

In [23] an adoptive pre-HO algorithm is suggested with the goal of providing seamless communications in heterogeneous networks. In this paper, user motion is predicted with "GaussMarkov" mobility model and according to the predicted Reference Signal Received Quality (RSRQ) the decision is made regarding start of HO process.

In the HO algorithm proposed in [5], GPS is used for position estimation. In this paper, user's movement direction angle is recorded in each step. For an angle variation of less than $60^\circ$ in one step, MN is assumed to move in the same direction as already did. Otherwise, every target network in the list will be eliminated, and a new list will be created according to the new direction. In this paper, to prevent the unnecessary handoffs, those HOs which take place in less than 0.5 seconds are aborted. TTT amount reduces at high speeds whenever HoFR increases, and at low speeds, TTT increases while the HoFR is increased.

In [12] user's residence time in target network has the highest impact on HO decision-making phase. In this paper user's direction change noticed by acquiring some flags to prevent Ping Pong Effect (PPE) and if user speed were less than HO time, that HO would be resisted. In [13] a double priority algorithm is designed, and HoFR is used for adjusting TTT values. They have tried to predict user's RSRP value to start the layer three HO before Layer two HO. In this work, user's propagation and speed effects used to propose a performance evaluating model. Also, an adoptable time window to avoid PPE is used in this paper. The main difference in this work and earlier solutions is that they used user's received signal power in previous steps for predictions instead of using thresholds and prevention timers.

In [10] an HO algorithm between LTE Femto and Macro cells proposed aiming to provide the highest possible throughput for users. In this work, Recursive Least Square Algorithm (RLS) method is used for predicting user's Received Signal Strength (RSS) in candidate target networks and by estimating SINR value they reduce the number of candidate networks.

In [11] an algorithm between LTE and WIFI networks proposed. In this paper at first stage, UE's RSS and speed are measured and by using a fuzzy logic algorithm according to SNR, BW, network load and available battery a network is peaked as target. This algorithm uses Mobile IP (MIP) as its basic HO process. In[19] HO algorithms are studied in multi-tier LTE networks and according to the results, it's revealed that on one hand, mobility based HO algorithms have less delay and computational complexity than other methods and On the other hand, these algorithms need to update user's location information continuously in short time spans.

In [14] another HO algorithm between LTE and WIFI networks is proposed. The offered method uses SINR values in different times during TTT and compares it with threshold SINR and according to that decides to start HO or not. In [25] a simple coefficient is used to reset the TTT value in different velocities according to the HoFR changes. Drawbacks of this method will be presented in the Evaluation Section.

To create seamless connections time-efficiency is one of the critical factors in Handoff (HO) algorithms. Various techniques been suggested for this purpose such as, using mobility models and tracking user location. These methods can be categorized in memory-based and memory-less groups. Memory-based algorithms keep user's location and speed information to be used for anticipating user's next location and speed. Other studies tried to calculate the user's received signal characters (*e.g.,* Strength, Noise, Jitter)) to foresee their Time of Stay (ToS) in the home or target networks. Finally, approximate location is used to define HO start time, which is crucial in time efficient algorithm designs.

One important aspect of HO algorithms is their operation domain. Adopted algorithms in heterogeneous networks, must consider differences between networks. As mentioned above, in the literature, various vertical HO algorithms designed for decision-making processes between LTE and WIFI (IEEE 802.11 a/g/n) networks.

Table I. OVERVIEW OF THE RELATED SOLUTIONS

| | **Networks** | **Method** | **Mobility Model** | **Parameters** | **Proposed Year** |
|---|---|---|---|---|---|
| **1** | LTE-WIFI | Fuzzy Logic | —— | TTT, BW, V, ToS | 2010 |
| **2** | LTE Pico Cells-Macro Cells | Prediction | Markov | RSRQ | 2014 |
| **3** | LTE | Utility Function | GPS, d | RSRP, TTT, HoFR | 2013 |
| **4** | WLAN-WIMAX | Utility Function and Flags | —— | ToS, UHO, HoFR | 2007 |
| **5** | LTE Femto Cells | Cross layer, Prediction | —— | TTT, RSRP, HoFR | 2012 |
| **6** | LTE Femto Cells | Memory based, Prediction | —— | P, UHO | 2010 |
| **7** | LTE Pico Cells-Macro Cells | Prediction | STEPS | SINR, TTT | 2014 |
| **8** | LTE-WIFI | Prediction | —— | V, TTT | 2014 |

## III. HANDOFF ALGORITHM DESIGN

In this paper, the focus is laid on a scenario in which a pedestrian user moves between LTE-A and IEEE 802.11ad networks. The proposed HO algorithm proposed is memory-and-time efficient and managed in a cross-layer fashion. Number of unnecessary HO and HoFR are reduced by managing TTT value. Location estimation is tried to be accurate and fast by modifying "Gauss-Markov" mobility model and LPP. In this algorithm , base and target networks and UE work together to calculate the parameters used in decision-making phase. To be computationally efficient, this algorithm does not continuously gather information from target and host networks. Finally, UE decides to start or deny the HO process based on her velocity, current TTT, RSRQ, and SINR.

### A. Assumptions

In this algorithm, an average walking speed of 1.4 m/s is assumed for a pedestrian user [21]. Based on the average speed, three categories of $\{v < 1, 1 < v < 3, 3 < v\}$ used for testing the HO algorithm. For the speed of $v < 1$ m/s, user is most probably changing location in slow fashion. In the speeds of $1 < v < 3$ user is walking in a range which most of the HOs may occur. Since the area covered by WiGig network is less than 20 m, walking in this range will increase unnecessary HOs or user is moving towards the LTE-A network. For the speed of $v > 3$ m/s, it can be assumed that the user is running or riding a bike or driving a car which all of them result in weak connection to WiGig AP and connection must be continued in LTE-A network.

Simulation area of the designed scenarios covered by one LTE-A eNB and includes one WiGig access point with radius of 15 m. LTE-A eNB and WiGig AP are calculating their available throughput and send to each other every time HO may occur. This data exchange happens while the MN is waiting for amount of TTT before starting the HO process. MN use one of four service types with data rate requests of {100 Mbps, 500 Mbps, 1 Gbps, and 3 Gbps} at the HO occurrence. At most 50 users in the simulation area are assumed.

### B. Moving From LTE-A to WiGig

As shown in the Figure 1, at first step, user's speed is calculated and if it was in the range of "High Speed" (*i.e.,* $v > 3m/s$) algorithm prevents the HO to take place. In the steps 2 and 3, SINR of the WiGig network and ToS of user in WiGig network declare how algorithm followed in the next steps. These values calculated by considering the next location of user according the Gauss-Markov mobility model. If the values of these two parameters satisfy the conditions simultaneously, then algorithm proceeds to next step.

In the step 4, HO process is being postponed for amount of TTT and until the TTT duration ends the whole or some parts of authentication and DHCP requests are already over. This is how the mobility prediction is done in the step 1 helps this algorithm to be time-efficient. After TTT ended, in the step 5 available throughput provided by target network is compared by the needed throughput (According to the service used by MN), and only if condition is fulfilled HO starts.

In this algorithm, processing load on home network is reduced by shifting the decision making role to UE side but, information gathering process is separated equally between home, and target networks as well as the UE.

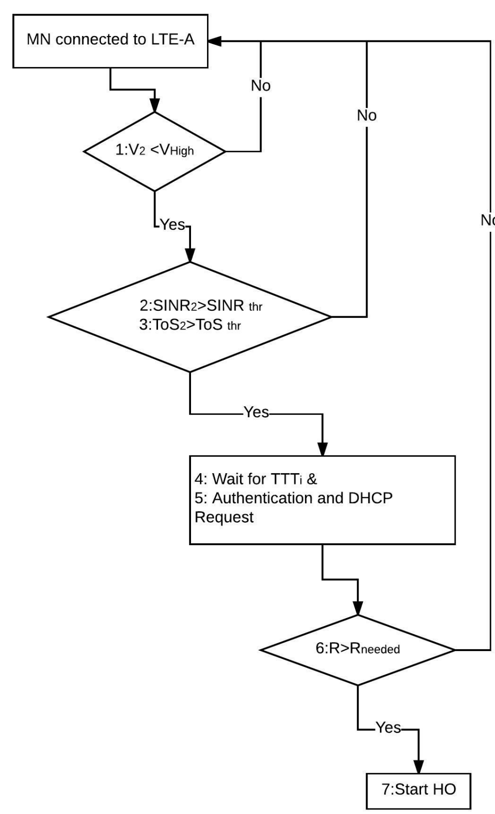


Figure 1. HO Process: Moving From LTE-A To WiGig

### C. Moving From WiGig to LTE-A

HO process while moving through WiGig to LTE-A is presented in the Figure 2. At first step, users speed is checked. While MN is connected to WiGig as the user is in indoor environment it seldom possible that user reaches to a speed above 3 m/s. However, in this condition (step 1.1) algorithm waits for the amount of TTT. If user's velocity is more than 3 m/s after the TTT, it shows that this condition is consistent and MN needs to connect to LTE-A without the need for further checks of other attributes. Even LTE-A available throughput control is not needed because in this speed, user's connection to WiGig is not logical and data loss is high.

In the second and third steps, RSRQ of LTE-A and SINR of WiGig in next time units are compared with their threshold values. At the $4^{th}$ and $5^{th}$ steps like the previous mode, algorithm forces the HO procedure to wait for TTT time. At the $6^{th}$ step, throughput is checked and at the $7^{th}$ step, algorithm starts the HO.

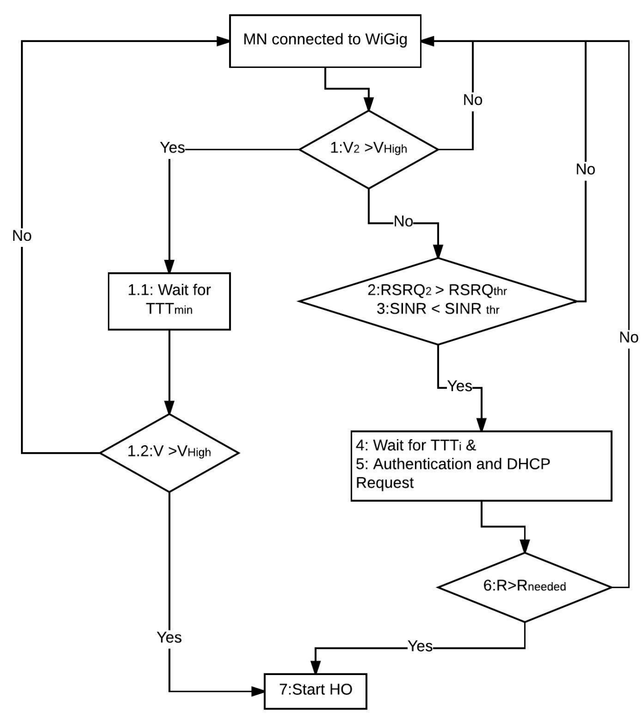


Figure 2. HO Process: Moving From WiGig to LTE-A

### D. Message Flow

In this Section, message-flows between different parties involved in the proposed HO processes are discussed. At first, lets suppose UE is connected to LTE-A network. To Start the HO process, some data exchanges occur as following. UE calculates it's ToS and WiGig's SINR and sends them in addition to it's mobility parameters to eNB (Figure III-D). Then eNB sends back the current TTT value which, is calculated according to data received from UE in advance. At this moment, HO start preprocessing as illustrated in Figure III-D.

In the next steps, probe message is sent by UE to WiGig AP (WG-AP) and after receiving ACK, authentication, DHCP, and

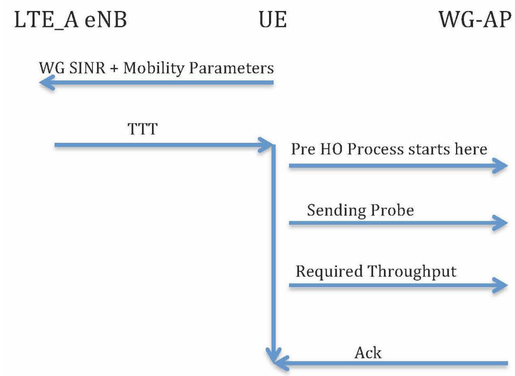


Figure 3. Parameter Exchanges

association requests are sent to AAA Server, WiGig Gateway, and Packet Data Network (PDN) Gateway respectively. After receiving answers(Acks), UE checks throughput availability of both networks at final step before connecting to the new network by sending its needed value to WG-AP and if the result is acceptable, UE connects to WiGig network.

In the second scenario, user is already connected to WG-AP, the above mentioned steps happen with this difference that in this condition, User's ToS is not considered and instead, RSRQ of LTE-A is measured. RSRQ is used in predicting the presence of MN in the area covered by WiGig. All the pre-connection communications happen in average in less than 200 ms [24].

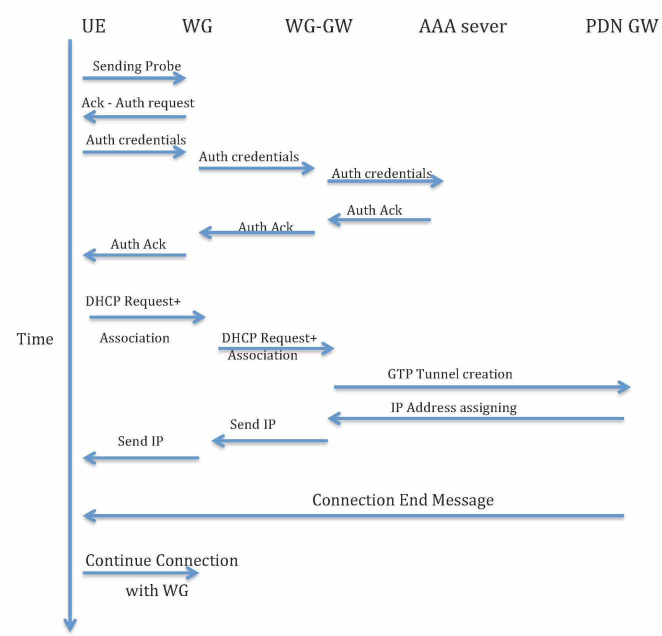


Figure 4. Message Flow of HO Process

Table II. TTT CHANGES ACCORDING TO HOFR AND VELOCITY STATUS

| Factor | User Velocity | TTT |
|---|---|---|
| $HoF_{i+1} > HoF_i$ | $1 < V_{UE} < 3$ | $TTT_i < TTT_{i+1}$ |
| $HoF_{i+1} > HoF_i$ | $V_{UE} < 1$ | $TTT_i > TTT_{i+1}$ |

## IV. PARAMETERS

In this part critical factors and parameters used in decision making phase of the proposed HO algorithm are declared and explained how to determine and calculate their values.

### A. Time to Trigger

Time to trigger is one of the fundamental parameters to calculate the exact time of HO process start and during recent years many different methods have been suggested for determining the value of this parameter [20]. Two major groups of these methods are the static and dynamic methods. In the static methods, there is a predefined and consistent value. In the Dynamic method, TTT is calculated according to the environment (network) and other parameters changes as the MN moves.

One of the most important parameters in calculating TTT is HoFR. In this paper HoFR amount in $i_{th}$ and $i-1_{th}$ moments and MN's velocity in $i_{th}$ moment are used to calculate the amount of TTT. In this paper 0.1 sec (100 ms) as the maximum and 0 sec as the minimum amount of TTT are determined. Binary search is employed to determine the value of new TTT at each step.

According to the Table IV-A, the value of TTT is reduced in different conditions by using equations 1 and 2. If MN is moving with a high speed ($1 < v < 3$) and HoFR is increased in the last two steps, TTT value should be decreased so the MN can move to the target network with less delay. Also, if the MN's speed is in the range of $v < 1$ and again the TTT value increases in the last two steps, the value of TTT needs to be increased so the user waits more until her moving pattern and condition becomes consistent.

$$TTT = (TTT + TTT_L)/2 \tag{1}$$

$$TTT = (TTT + TTT_h)/2 \tag{2}$$

Most of the Fast Handovers for Mobile IPv6 (FMIP) algorithms take almost 200 ms to associate in the target network and get a new IP address. Since the maximum amount of TT s set to 100 ms in the proposed algorithm, it can be used in any kind of(Media Independent Handover) MIH, FMIP and Proxy Mobile IP (PMIP) protocols and generally it is compatible with the IEEE 802.21 protocol.

### B. Time of Stay

In order to predict the time user will stay in WiGig environment TOS parameter is calculated based on the Equation 3.

$$ToS = \frac{R - (L_W G - L_M N)}{(V_{t1} + V_{t2})/2} \tag{3}$$

In this Equation R is the radius of WiGig network which is 15-20 m, $L_W$ is the location of WiGig AP, $L_M$ is the location of MN and $V_1$ and $V_2$ are User velocity in $t_1$ and $t_2$ time units.

### C. Reference Signal Received Quality

In this paper, RSRQ is used as an indicator of signal quality in LTE-A [7]. For estimating this variable 4 and 5 Equations are used.

$$RSRQ = N * RSRP/RSSI \tag{4}$$

$$RSSI = S_{tot} + I_{tot} + N_{tot} \tag{5}$$

In these formulas, N represents the rate of used resource blocks. RSRP is the Reference Signal Received Power and RSSI is the Received Signal Strength Indicator. In RSSI calculation, $S_{tot}$ is Signal power, $I_{tot}$ is Interference and $N_{tot}$ is Noise all in their total amount.

### D. Path Loss

In this work, to estimate the Path Loss values in LTE-A, COST231-Hata model is employed as shown in the Equations 6 to 8. Also, for the same purpose the Log Normal Shadowing method is used for the WiGig network as shown in the Equation 9 [15].

$$L_P = A + BLog(d) + C \tag{6}$$

$$A = 46.3 + 33.9Log(f_c) - 13.82Log(h_M) - a(h_u) \tag{7}$$

$$B = 44.9 - 6.55Log(h_M) \tag{8}$$

In these equations $f_c$ is the $LTE-A$ frequency and $h_M$ and $h_u$ are $LTE-A$ antenna and user equipment height [16]. Amount of these variables are indicated in the Table IV-F.

$$L_p(d) = \overline{PL}(d_0) + 10nlog(d/d_0) + X_\delta \tag{9}$$

In reference distance of 1 meter in 60 GHz ($\overline{PL}(d_0)$) is equal to 68 dB. $X_\delta$ is the Gaussian random variable with average amount of $\mu$ and standard deviation of $\delta$. In this paper values of n and $\delta$ are considered equal to 2.44 and 0.88.

### E. SINR in WiGig

In current paper Additive White Gaussian (AWG) noise model is used in order to estimate the SINR value [9] as presented in the Equation 10 and 11.

$$P_n(w) = randi(0, N_t/2) \tag{10}$$

$$N_t = k_b * B * 290 \tag{11}$$

In the Equations 10 and 11, $P_n$ is the Thermal noise power which is determined with the *randi* function and $N_t$ is the thermal noise power in Watts and $k_b$ is Boltzman constant and equals to $1.38*10^-23$ and B is the WiGig BW. We use general function of SINR calculation as mentioned in the Equations 12 and 13.

$$\gamma = P_r/(I+N) \tag{12}$$

$$P_r = P_t - L_p(d) \tag{13}$$

In the Equation 12, $P_r$ is the Received Signal Power, $P_t$ is WiGig antenna transmission power and $L_P$ is the Path Loss. $I$ represents the interference amount which is eliminated in this paper because there are no interference between WiGig and LTE-A frequencies according to their different frequency ranges of operation. Also, SINR threshold of 25 dB is considered for 7 Gbps of throughput [17] in WiGig network.

### F. Mobility Model

The Gauss-Markov mobility model is employed in order to estimate the user's next location. In this method, user's next velocity and movement direction is calculated by relations shown in the Equations 14 and 15 [17].

$$s_n = \alpha s_{n-1} + (1-\alpha)\bar{s} + \sqrt{1-\alpha^2}s_{x_{n-1}} \tag{14}$$

$$d_n = \alpha d_{n-1} + (1-\alpha)\bar{d} + \sqrt{1-\alpha^2}d_{x_{n-1}} \tag{15}$$

In these Equations, $s_n$ and $d_n$ are user speed in $n_{th}$ time unit. $\alpha$ is the randomization factor in the range of [0,1]. $s$ and $d$ are average amount of speed and direction when n, $s_{x_{n-1}}$ and $d_{x_{n-1}}$ are random Gaussian values with mean value of 0.

Fully random values are reachable by setting the $\alpha$ equal to 0 and linear values are reachable by setting the $\alpha$ equal to 1. In this paper value of $\alpha$ is set to 0.5. Values of MN location in next step are calculated by the Equations 16 and 17 [4].

$$x_n = x_{n-1} + s_{n-1}\cos d_{n-1} * 1 \tag{16}$$

$$y_n = y_{n-1} + s_{n-1}\sin d_{n-1} * 1 \tag{17}$$

In the Equation 16, $x_n$ is the MN location in "X" axis which is calculated by using the velocity of MN in "X" axis multiplying by time step and can be omitted as far as it equals to 1. By adding this quantity to $x_{n-1}$ which is MN's last location in the "X"axis, new location is estimated. For "Y" axis, user's location is accessible using Equation 17, the same as "X" axis.

Incentives of selecting the "Gauss-Markov" mobility model are as follows; First, this model avoids irregular random movements which are not logical for a pedestrian user moving behavior. Second, this model requires only small amount of memory in order to keep the last and average speed and direction of user. Third, computational complexity of this method is acceptable and has no heavy overload on user's device [4].

While the MN is connected to LTE-A network, LTE Positioning Protocol (LPP) [8] provides the location of user. This information is used to improve the "Gauss-Markov" mobility model precision by comparing the last prediction and the exact location using Equation 20.

$$L_n = (\alpha L_{n-1} + (1-\alpha)\bar{L} + \sqrt{1-\alpha^2}L_{x_{n-1}})\bar{\gamma} \tag{18}$$

$$\gamma = (L-l)/l \tag{19}$$

$$\bar{\gamma} = \frac{\lambda\gamma + \beta\bar{\gamma}}{\lambda+\beta} \tag{20}$$

In the Equation 20, $L$ is the exact location of MN known by LPP and $l$ is the estimated location in previous step using "Gauss-Markov" mobility model. $\gamma$ is variation of $L$ and $l$ to amount of $l$ and $\bar{\gamma}$ is the weighted average of $\gamma$ previous $\bar{\gamma}$ in each step and $\lambda = 0.1$ and $\beta = 0.9$ which are given weights and we prefer to augment the effect of $\gamma$ to smooth the user's movement. In this work, by facilitating the normal Gauss-Markov model with the information gathered by LPP, the accuracy of mobility model prediction used in this HO algorithm is enhanced.

Simulation of the proposed HO algorithm in this paper is done with MATLAB. Simulation environment is characterized with parameters and values as summarized in the Table IV-F. As mentioned in Section III-A, Scenarios studied in this work include one LTE-A and one WiGig AP antenna each. Specific variables for "Path loss", "Noise Effects", and "SINR" calculation are presented in table IV-F.

Table III. SIMULATION PARAMETERS

| Simulation Parameters | Symbol | Value |
|---|---|---|
| **eNB Number** | $N_{LTE}$ | 1 |
| **WG-AP Number** | $N_{WG}$ | 1 |
| **Simulation Duration** | $T_{sim}$ | 1000 s |
| **RSRQ Threshold** | $RSRQ_{th}$ | 19.5 dBm |
| **SINR Threshold** | $SINR_{th}$ | 25 dB |
| **LTE-A eNB Transmission Power** | $P_{LTE}$ | 30 dBm |
| **WG Transmission Power** | $P_{WG}$ | 10 dBm |
| **LTE-A Bandwidth** | $B_{LTE}$ | 100 MHz |
| **WG Bandwidth** | $B_{WG}$ | 2160 MHz |
| **LTE-A Antenna Height** | $h_{eNB}$ | 40 m |
| **WG Antenna Height** | $h_{WG}$ | 1.5 m |
| **Mobility Model** | ——– | Gauss-Markov and LPP |
| **Initial TTT** | $TTT_i$ | 0.1 s |
| **LTE Frequency** | $f_{c-LTE}$ | 2100 MHz |
| **WG Frequency** | $f_{c-WG}$ | 60 GHz |
| **LTE Radius** | $LTE_r$ | Whole Simulation Area |
| **User Velocity** | $V_u$ | $[0-5]m/s$ |
| **Data Transfer Direction** | ——– | Downlink |
| **Number of LTE users** | $N_{U-LTE}$ | (1-50) |
| **Number of WG users** | $N_{U-WG}$ | (1-50) |

Table IV. SPECIFIC VARIABLES FOR PATH LOSS, NOISE AND SINR CALCULATION

| Network | Parameter | Value |
|---|---|---|
| **LTE** | $f_c$ | 2100 MHz |
| | $h_U$ | 1.5 m |
| | $h_{eNB}$ | 40 m |
| **WiGig** | $G_t$ | 1 dB |
| | $G_r$ | 1dB |
| | $\lambda$ | 5 mm |
| | N | 2 |
| | $\delta$ | 1 |
| | $d_0$ | 1 m |

## V. EVALUATION

In the Figure V, user movement is shown in 1000 sec of simulation run. The circle is the area covered by both WiGig and LTE-A with diameter of 40 m. While the entire area is under coverage of LTE-A. In each simulation run, user's initial location is chosen randomly and each star points a HO occurrence.

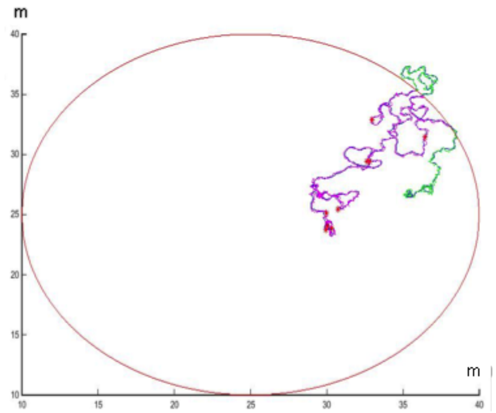


Figure 5. User Movement in 1000 s with Gauss-Markov mobility model and LPP

In Figure VI, the TTT variation is shown in part of the whole simulation (from 130 to 230 seconds) and the proposed HO algorithm handles the HoFR by keeping the value of HoFR equal to 0, which means the proposed algorithm keeps the HO failures equal to zero. In this paper HO failure is defined by the number of HOs happen in the amount of TTT. HO failure with this definition represents the HOs happened as a result of PPE. In this image stars show the time, when a HO is happened.

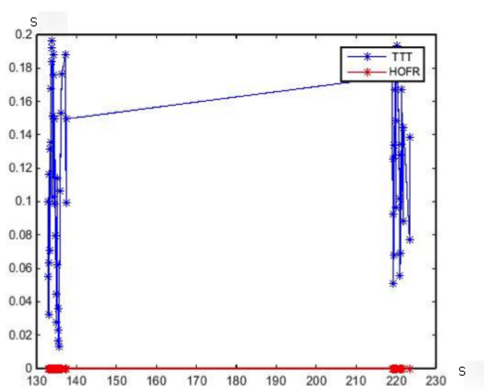


Figure 6. TTT variation by keeping HoFR =0

In Figure VII, the algorithm suggested in [25] is used and according to this algorithm's performance in this scenario, it is visible that this algorithm can't respond in situations with combination of WiGig and LTE networks since the TTT increases up to 18 sec in order to show the same reaction to HO failures and keeping the HoFR close to 0.

In Figure VIII, results of algorithm proposed in [25] illustrated in the same scenario with user velocity of less than 1 m/s. Obviously this algorithm is not designed for this situation and it is not capable of controlling the HoFR.

In comparison with algorithm presented in [5], even though TTT is determined dynamically in this algorithm but, TTT

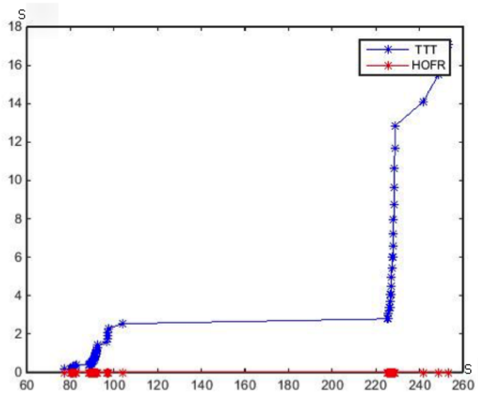


Figure 7. TTT Variation Using Method of [23] With User Velocity Larger than 3 m/s.

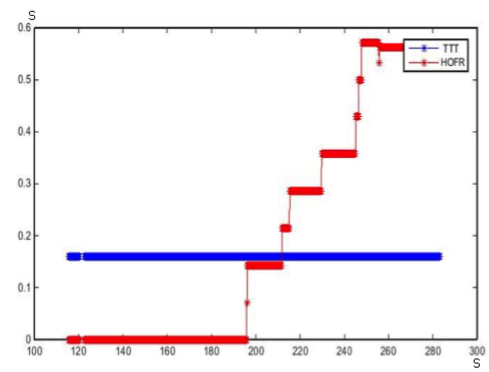


Figure 8. TTT Variation Using Method of [25] With User Velocity Larger than 1 m/s.

fluctuates between 0 to 5 sec according to LTE standard. Besides, waiting for 18 sec is far beyond time efficiency. If TTT = 2 sec, average amount of lost data in LTE-A with data rate of 3 Gbps in downlink is almost 6 Gb in 2 seconds and it is even worse in WiGig. In this algorithm user's direction changes are recorded and, it will cause computational and memory costs. In the Figure IX HO algorithm proposed in [23] is used and again it is clearly obvious that this algorithm fails in this scenario as the HoFR is constantly increasing.

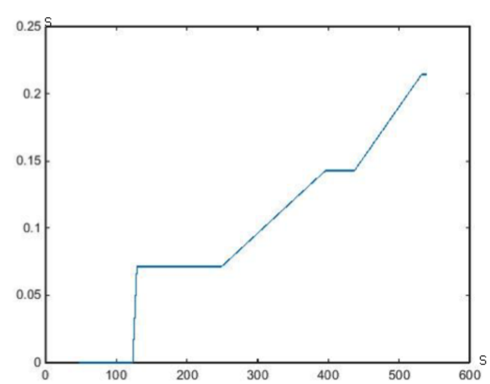


Figure 9. TTT Variation Using Method of [23]

## VI. CONCLUSION

LTE-A R12 is capable of supporting up to 3 Gbps and IEEE 802.11ad (WiGig) with up to 7 Gbps in downlink, thus, it can be a possible choice of 5G wireless communication for users of cellular and local wireless networks. In support of these technologies, a new cross-layer vertical HO algorithm was presented, which provides seamless connectivity between LTE-A and WiGig networks.

Since computations and processes are separated between UE, home network, and target networks a reduction of the load on one part was reached. The algorithm reacts to HoFR increase by adjusting the TTT value. Besides lowering the computational complexity, a binary search is used in TTT calculations to provide faster converges than with a linear method by the order of O(log(n)), which leads a very practical application. To the avoid continuous monitoring of various parameters, this algorithm specifies a high priority to users' velocity. For that reason, checking other variables such as SINR, RSRQ, and TTT is done only, if the user's velocity is in a specific range. Being sensitive to the user's velocity, this new algorithm performs better in comparison to other HO algorithms, especially within the decision making phase for high user velocities.

Additionally by being a proactive algorithm, users' mobility, including their next location, speed, and angle of movement, are estimated using the Gauss-Markov mobility model, which is updated and readjusted by the accurate data received from LPP. This update increases the precision of the Gauss-Markov model for upcoming estimations. Also, this model is applicable practically, since it is not memory bounded and with only few bytes of memory the user's exact location can be estimated.

Finally, a comparison with similar algorithms revealed that these other algorithms cannot be used in scenarios with a goal of time-efficiency and without data loss during a HO between LTE-A and WiGig networks. High (or constantly increasing) TTT values of other algorithms make them inappropriate to be used for managing the HO processes for these scenarios and in most cases HoFR could not be controlled and reduced by them.

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