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Performance Evaluation of UMTS-WLAN interworking

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***Abstract*—** The main methods used to implement WLAN-3G inter working are: the mobile IP methods, the emulator method, and the gateway method. Each one of these methods enjoys some pros and suffers from some cons. In this paper, It is demonstrated to evaluate certain aspects of WLAN-3G inter working. Here, case studies are addressed: based on results of the current researches and some simulations developed in this paper; in order to evaluate some aspects of inter working methods. Basically, in this paper, the main methods used to implement WLAN-3G inter working are evaluated from the handover delay point of view. It is seen how each method behaves in the case of handover and how long the user waits in case of hand-over between WLAN-3G service areas. All of these methods are compared were compared**.**

***Keywords*— UMTS, WLAN, Interworking.**

I. INTRODUCTION

According to 3GPP Release 6 [1], the intent of WLAN-3G inter working is to extend 3G services and functionality to WLAN access environment. Thus WLAN effectively becomes a complementary radio access technology to 3G. WLAN can provide high data rates capabilities and 3G can provide high mobility capabilities. WLAN-3G Inter working is used generally to refer to the inter working between 3G system and WLAN family of standards. This means combining or integrating both of WLAN and 3G technologies altogether to utilize the benefits of them.

Thus, the new WLAN-3G inter working system will combine both of these key capabilities: high data rate and high mobility together. WLAN-3G inter working addresses the new generation technology that covers the increasing ubiquitous public wireless user demands for high data-intensive applications and enables smooth online access to corporate data services in hot spots.

The main architectural methods, which are proposed, for integrating WLAN and 3G technologies together are:

- The mobile IP architectural method
- The gateway architectural method
- The emulator architectural method

Details on architectural methods, handover procedure and advantages & limitations of each of above method can be found in [2]. In this paper some simulation will be demonstrated to evaluate certain aspects of WLAN-3G inter working. Here, case studies are addressed: based on results of the current researches and some simulations developed in this paper; in order to evaluate some aspects of inter working methods. Basically, in this paper, the main methods used to implement WLAN-3G inter working will be evaluated from the handover delay point of view. It will be seen how each method behaves in the case of handover and how long the user waits in case of hand-over between WLAN-3G service areas. All of these methods will be compared as well.

The rest part of this section will introduce to the evaluation metrics for evaluating 3G-WLAN inter-working methods as will be seen later in this paper. Wireless networks differ from wired networks in the access technologies and the characteristics of the transmission medium. In this section some important characteristics of the wireless medium, which affect quality of service (QoS) of wireless networks, will be pointed out [3].

II. TERMINOLOGY

This section gives a brief terminology used in this paper.

A. Wireless Topology

The wireless network consists of wireless access points called Base Station (BS) in 3G or AP in WLAN, where each access point covers a certain geographical area. Frequency reuse is used in some wireless technologies such as GSM. However, in WCDMA, the frequency reuse factor equals to one.

B. Mobility

User mobility and wireless topology are the reasons why handover is necessary. Moreover, a wireless mobile user frequently changes its location; thus resulting in time varying bit error ratio and interference, which directly defines the QoS of the wireless network.

Handover schemes have what so called handover latency or handover delay. This is the time period during which the wireless mobile user is unable to send or receive IP packets or calls. In certain scenarios such as mobile IP – as will be seen later in this paper the handover delay may be greater than what is acceptable for real time services. Also, handover may cause packet losses or call dropping. Such losses may disrupt both real time and non real time services, and hence are undesirable.

User mobility introduces another problem: location control. It is necessary to track the wireless mobile users within the wireless network. Certain location management schemes are used in wireless networks for keeping track of wireless mobile users.

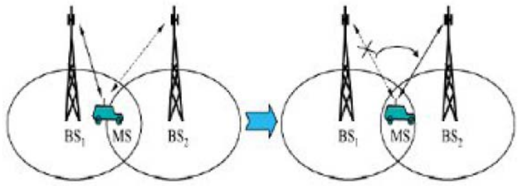

Fig.1: Hard Handover in Wireless Cellular Networks

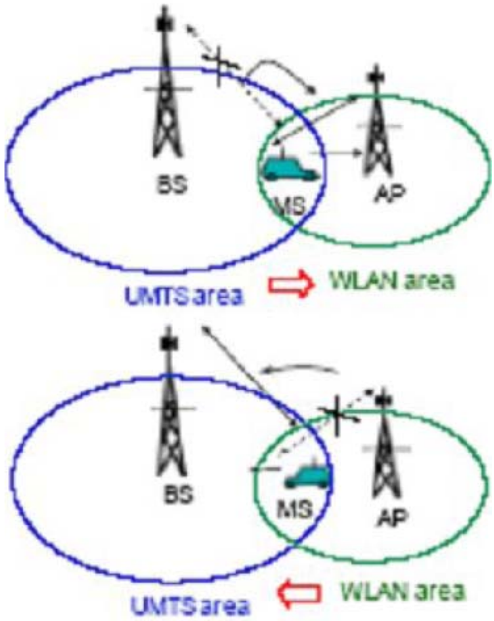

Fig. 2: Handover Scenarios in UMTS-WLAN

C. Bit Error Rate (BER)

Bit error in wireless links may occur due to different causes such as: interference, interference noise, multi-path fading, and shadowing.

Fading or path loss is one of the main characteristics of signal propagation over a wire-less link. One general formula for path loss is given in the following equation:

$$L = \frac{P_R}{P_T} = c\frac{1}{f^2 d^\alpha}$$

Where,

P_R : is the received power at the receiver (the wireless access point or the wireless mobile user)

P_T : is the transmitted power at the transmitter (the wireless access point or the wireless mobile user)

f : is the frequency

d : is the distance between the transmitter and the receiver

α : is a factor depends upon the characteristics of the wireless medium usually indicated as the path loss exponent. Typical values lie between 3 and 5.

c : is a constant.

Shadowing is a result of obstacles on the path of the radio waves (i.e. there is no line of sight between the wireless access point and the wireless mobile user). Furthermore, due to the reflection of the signal from surrounding objects such as buildings, different parts of the same signal may arrive to the receiver via different paths. This leads to what is called multi-path effect. Multi-path is not desirable in some wireless networks such as GSM while it is helpful in other wireless networks such as WCDMA. Interference is a result of the reuse of the same or adjacent frequency bands in the same of neighbouring cells. WCDMA networks are robust to the interference due to the orthogonal spreading codes of the narrow band signals over wide frequency spectrum. The above characteristics of the wireless medium determine the bit error. Also, the bit error rate depends on the location of the wireless mobile user. Therefore, all of these factors have to be taken into account in the design of wireless networks.

III. HANDOVER IN WIRELESS NETWORKS

Since handover delay is the main feature, which will be used in the evaluation of WLAN-G inter working methods, firstly, an overview about handover in wireless networks will be presented in this section. As described above, mobility is the most important feature of a wireless network. Usually, continuous service is achieved by supporting handover (or handoff) from one cell to another. Handover is the process of changing the channel (frequency, time slot, spreading code, or combination of them) associated with the current connection while a call is in progress. It is often initiated either by crossing a cell boundary or by deterioration in quality of the signal in the current channel. Poorly designed handover schemes tend to generate very heavy signaling traffic and, thereby, a dramatic degrades in QoS. The reason why handovers are critical in wireless networks is that neighboring cells are always using a disjoint subset of frequency bands, so negotiations have to take place between the wireless mobile user, the current serving wireless access point, and the next potential wireless access point. Other related issues, such as decision-making and priority strategies during overloading, might influence the overall performance. Handover is divided into two broad categories:

- Hard handovers: in which current resources are released before new resources are used. This is further divided into intra-cell and inter-cell handovers.
- Soft handovers: in which both existing and new resources are used during the handover process. This is further divided into soft handover and softer handover.

In a hard handover, the link to the prior wireless access point is terminated before or as the wireless mobile user is transferred to the new cell's wireless access point; the wireless mobile user is linked to no more than one BS at any given time. Figure 1 illustrates hard handover between the wireless mobile user (MS in this case) and the wireless access point (BS in this case) in wireless cellular network. In this figure, MS moves from one BS (BS1) to another (BS2). Here, the mean signal strength of BS1 decreases as the MS moves away from it. Similarly, the mean signal strength of BS2 increases as the MS closer to it.

A hard handover occurs when the old connection is broken before a new connection is activated. The performance evaluation of a hard handover is based on various initiation criteria such as:

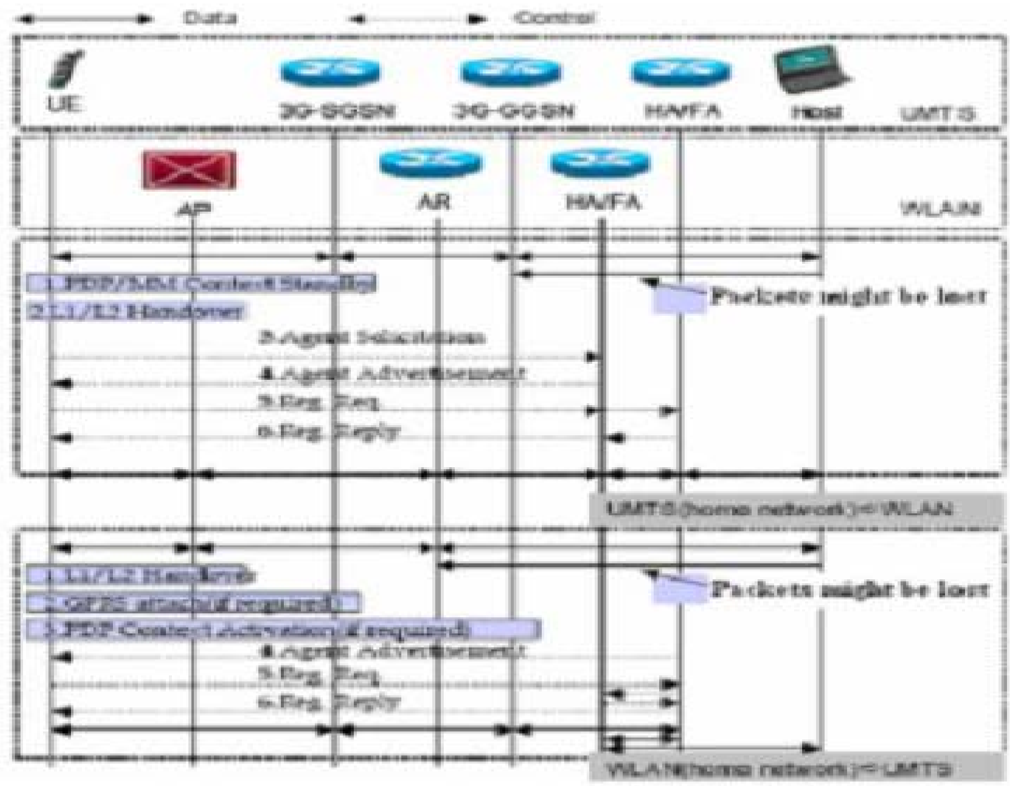

Fig.3: WLAN-3G Handover using mobile IP method [2]

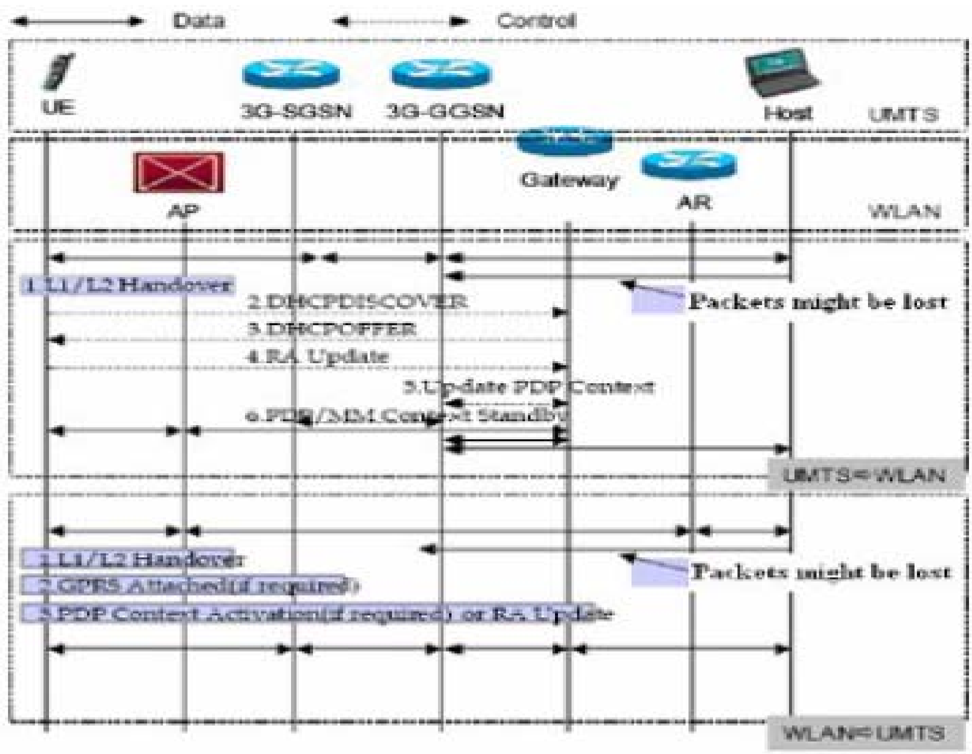

Fig.4: WLAN-3G Handover using Gateway method [2]

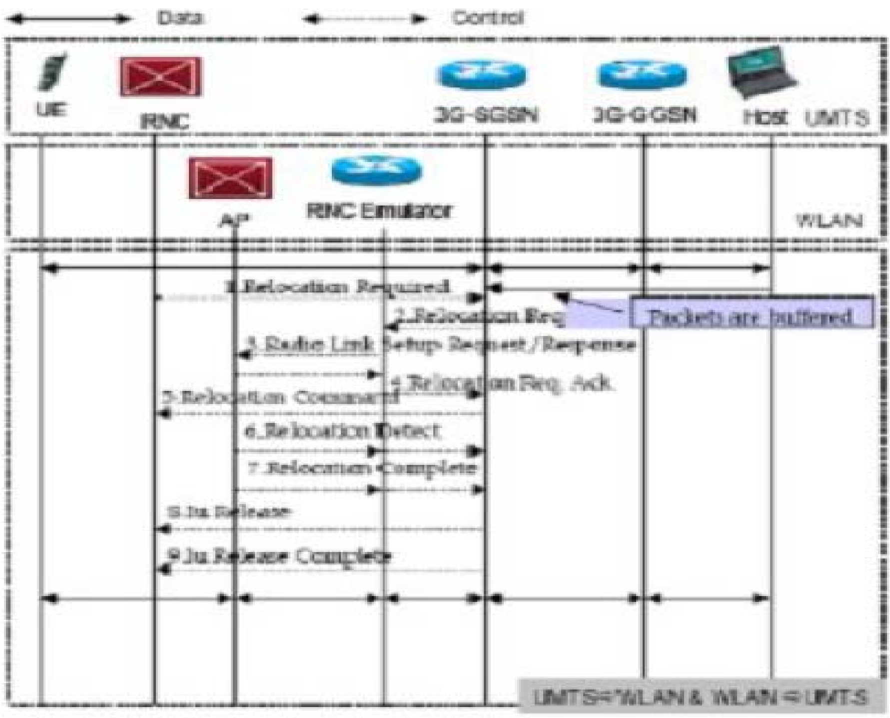

Fig.5: WLAN-3G Handover using Emulator method [2]

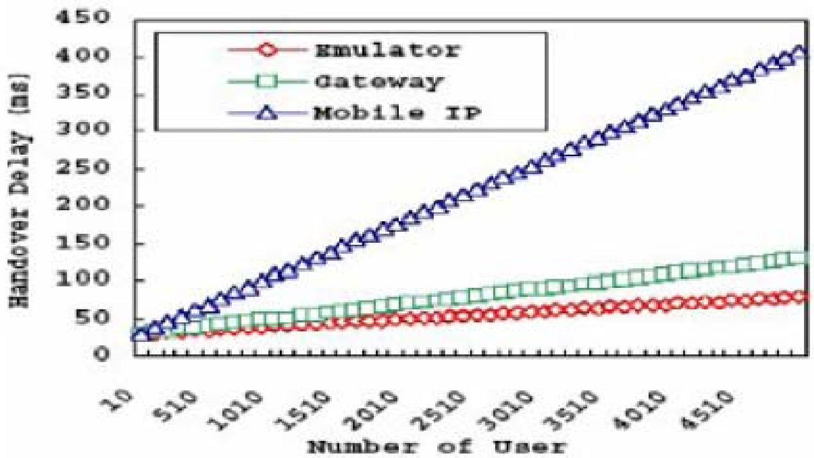

Fig.6: Handover delay for different WLAN-UMTS interworking methods

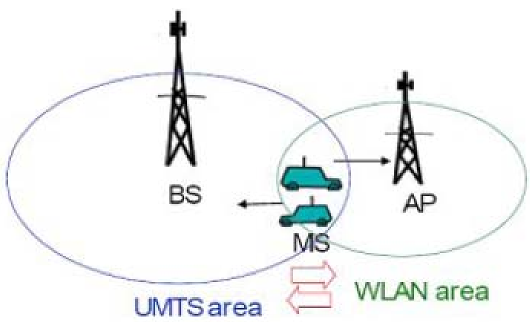

Fig. 7: The System Model

- **Relative signal strength**: in this method the strongest received wireless access point (BS) is selected at all times. The decision is based on measurement of the mean of the received signal. This method is observed to provoke too many unnecessary handovers, even when the signal of the current wireless access point is still at an acceptable level.
- **Relative signal strength with threshold**: This method allows a wireless mobile user (MS) to handover only if the current signal is sufficiently weak (less than certain threshold) and the other is the stronger of the two.

Basically, in this paper, the hard handover is considered. The relative signal strength with threshold will be used as handover initiation criteria.

Reference to the handover in UMTS-WLAN inter working system, there are two hand-over scenarios as illustrated in Figure 2:

- **BS to AP scenario**: the wireless mobile user (MS) moves from UMTS area towards WLAN area leaving its previous serving wireless access point (BS) and approaching the new hosting wireless access point (AP).
- **AP to BS scenario**: the wireless mobile user (MS) moves from WLAN area towards UMTS area leaving its previous serving wireless access point (AP) and approaching the new hosting wireless access point (BS).

These handover scenarios will be used in evaluating 3G-WLAN inter working methods.

IV. Performance Analysis

A. *Performance Metrics*

There are several performance metrics that can be used to quantify the performance provided by a particular WLAN-3G inter working method. However, the following main performance metric will be used in evaluation the performance of such inter working methods:

- *Handover delay*: is the time between the initialization and the end of the handover between BS and AP. It is the time the wireless mobile user (MS) needs to wait until the handover process is completed among BS-AP. The handover delay, D_h can be formulated as:

$$D_h = D_t + D_W$$

Where,

D_t : is the time spent in transmission between MS and AP/BS

D_W : is the waiting time spent in handover processing in the network.

In addition to handover delay performance metric, another parameter will use in the evaluation process such as: number of handovers between WLAN- UMTS networks, number of dropped calls between WLAN-UMTS networks.

Handover Delay in the Inter working Methods

As described in the previous chapter, various methods are used to implement WLAN-3G inter working. Each method has its own architecture and applies its own handover procedure. Mainly, the handover delay issue will be explained for the mobile IP method, the gateway method, and the emulator method and also these methods will be evaluated based on such performance metric. The handover delay consists of two parts: the delay due to transmission and the waiting delay due to handover processing. The handover delay part due to transmission is common to all inter working methods since it depends only on the distance between MS and AP/BS; thus it can be eliminated from the comparison of inter working methods. However, the waiting delay due to handover processing is dependent on the network itself and the various involved components.

Therefore, this part cannot be eliminated from the comparison of inter working methods. It represents the key part of the hand-over delay. The handover delay differs from one inter working method to another. In the mobile IP method, see Figure 3, the various components of the waiting delay can be deduced as follows:

- In case of UMTS to WLAN handover, the waiting delay, D_W , is the sum of:
  - D_1: the time spent in PDP/MM context standby and L1/L2 handover data among UE, 3G-SGSN, 3G-GGSN, and host
  - D_2 : The time spent in agent solicitation, advertisement, and registration controls among UE, WLAN HA/FA and UMTS HA/FA.
- In case of WLAN to UMTS handover, the waiting delay, D_W , is the sum of:
  - D_1': the time spent in GPRS attach, PDP/MM context activation, and L1/L2 handover data among UE, AP, AR, and host.
  - D_2': the time spent in agent advertisement, and registration controls among UE, WLAN HA/FA and UMTS HA/FA.

In the gateway method, figure 4, the various components of the waiting delay can be deduced as follows:

- In case of UMTS to WLAN handover, the waiting delay, D_W, is the sum of:

  D_3 : The time spent in L1/L2 handover data among UE, 3G-SGSN, 3G GGSN, and host.

  D_4 : The time spent in DHCP setup, RA update and PDP context controls among UE, Gateway, 3G-SGSN, and 3G-GGSN.
- In case of WLAN to UMTS handover, the waiting delay, D_W, equals:

  D'_3: The time spent in GPRS attach, PDP/MM context activation, and L1/L2 handover data among UE, AP, AR, host, and 3G-GGSN.

In the gateway method (Figure 5), the components of the waiting delay can be deduced as follows:

- In case of UMTS to WLAN handover or WLAN to UMTS handover, the waiting delay, D_W, equals:

D_5 : The time spent in L1/L2 handover data among UE, 3G-SGSN, 3GGGSN, and host.

The previous analysis is summarized in the following relation:

$$D_w = \begin{cases} D_1 + D_2, \cdots\cdots\cdots\cdots umts \rightarrow wlan : mobile IP \\ D_1' + D_2', \cdots\cdots\cdots\cdots wlan \rightarrow umts : mobile IP \\ D_3 + D_4, \cdots\cdots\cdots\cdots umts \rightarrow wlan : gateway \\ D_3', \cdots\cdots\cdots\cdots\cdots wlan \rightarrow umts : gateway \\ D_5, \cdots\cdots umts \rightarrow wlan / wlan \rightarrow umts : emulator \end{cases}$$

As a rough estimate comparison, the handover processing components can be used to give a general indication about inter working methods assuming all components have the same conditions.

For the mobile IP method and the gateway method, D_1 is greater than D_3since they access the same components but D_1 involves more data to be processed. D_2 is greater than D_4 since in D_2 , the processing occurs in the same UMTS network while it involves both WLAN network and UMTS network in D_4. Moreover, $D'_1$is approximately similar to D'_3. Thus, the waiting delay in the mobile IP method is greater than that in the gateway method.

For the emulator method, the waiting delay involves only one item, which is processed in the same network since WLAN is considered as one cell of UMTS network so the handover is performed as it is within the UMTS network. Thus, it is expected that the emulator method have lower waiting delay than the mobile IP method and the gateway method.

To summaries above, the emulator method has the lowest handover delay among the three inter working methods, and then comes the gateway method and then lastly the mobile IP method.

B. *Performance Observations*

This section demonstrates some performance studies of the three inter working methods. This is based on some popular works in line with this topic [2, 4]. Although those publications are concerned with inter working methods in different simulation network architectures and traffic models than what used here, some results can be *safely generalized* to the system model used here.

Furthermore, these performance studies will be used to validate the system model and to prove or confirm the deduced results and the drawn conclusions.

The performance studies in [2 & 4] are based on simulations. One simulation, which will be described here, will be used to confirm deduced results and the drawn conclusion.

The simulation environment for this simulation has a UMTS network and a WLAN network implemented using NS2, which developed by UC Berkeley. The simulation parameters are following:

- UMTS network has a 100 Mbps backbone with 5 radio network subsystems and offers 32 kbps data services.
- WLAN has 25 AP's and provides 100 kbps data service.
- It is assumed that 50 % of the users are WLAN users and the other 50 % of the users are UMTS users.
- Among all users, 50 % are dual mode users and might move in between two networks, and the other 50 % are single mode users using either WLAN or UMTS.
- Dual mode users have a 0.5 probability to enter WLAN network and a 0.5 probability to enter UMTS network.

The three different inter working methods are compared here, i.e. the mobile IP method, the gateway method and the emulator method. Figure 6 shows the handover delay for those inter working methods. It is clear that the mobile IP method obtains the poorest performance since the signaling packets have to go to Internet (HA/FA). Also, the mo-bile IP method introduces more than 200 ms delay under this network configuration while the users are more than 2000. The delay might not be acceptable for real-time applications.

The gateway method and the emulator method involve the message exchange within intra-network only. The latency of the gateway method is a little bit higher than in the emulator method.

The result of this performance study confirms with the expected results obtained from the handover delay analysis in the previous section.

V. SIMULATIONS

In this section, a simulation model is developed using MATLAB to evaluate UMTSWLAN inter working methods: the mobile IP method, the gateway method, and the emulator method. The simulation environment, parameters, assumptions, and approach are illustrated here.

A. *System Model*

The system model used in the simulation consists of a UMTS network and a WLAN being inter worked using the three inter working methods. Each network has a single wireless access point, i.e. UMTS has a single BS and WLAN has a single AP. The coverage area of each wireless access point is a circle with radius *R* and the wireless access point is located at the center of the coverage area. It is not necessary that both coverage areas are equal. Figure 7 shows the coverage areas for BS and AP.

Each network has its own users, which are uniformly distributed, among the coverage area. The wireless mobile users (MS) can move freely between both networks.

The position of a MS is defined with r and φ coordinates (indirectly x,ycoordinates), where r is the distance from the center of the area and φ is the angle with the horizontal axis. The power distribution function (pdf) for the user density in the area is given by:

$$f_r(r) = \begin{cases} \frac{2r}{R^2} & 0 < r < R \\ 0 & r > R \end{cases}$$

Also, the pdf for φ is given by:

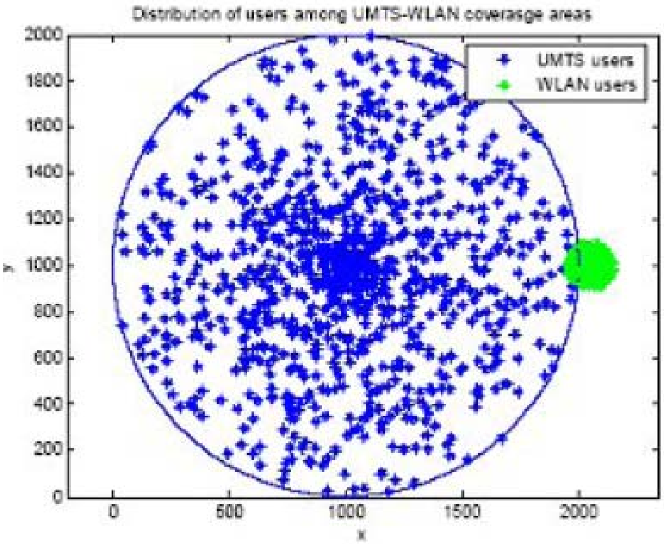

Fig. 8: System Model (Distribution of users among WLAN-UMTS Area)

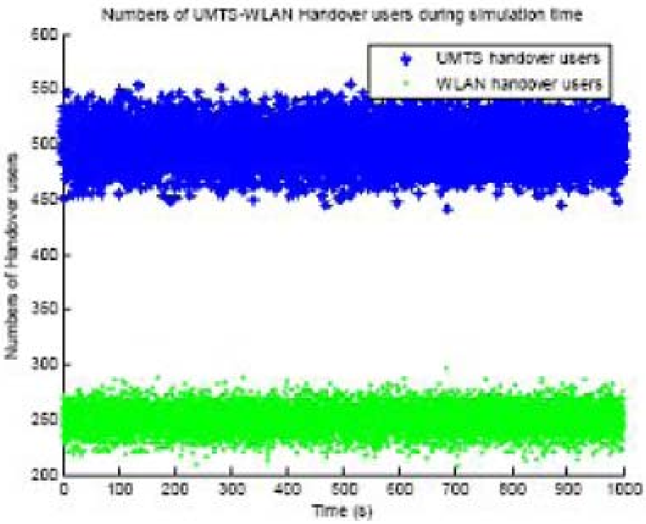

Fig. 9: Number of WLAN-UMTS handover users

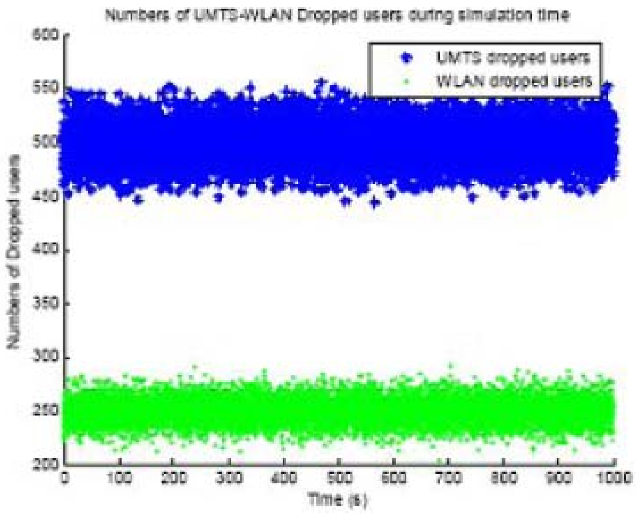

Fig. 10: Number of WLAN-UMTS dropped users

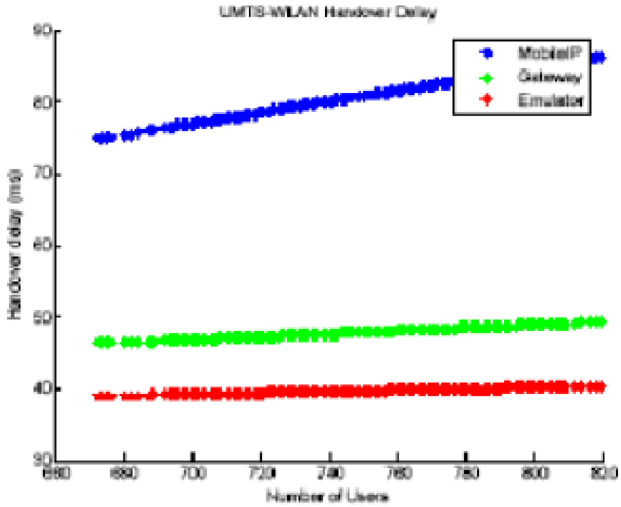

Fig. 11: Handover delay for different interworking method

$$f_{\varphi}(\varphi) = \frac{1}{2\pi} \qquad 0 \le \varphi \le 2\pi$$

In this model, the movement direction and the magnitude of the velocity, v of the users are assumed to remain constant within one simulation time step; these are allowed to change at handover to the other area. The pdf for $\theta$is given by:

$$f_{\theta}(\theta) = \frac{1}{2\pi} \qquad 0 \le \theta \le 2\pi$$

The pdf for the velocity is given by:

$$f_v(v) = \begin{cases} \frac{k}{2\pi u} e^{-\frac{(v-m)^2}{2\sigma^2}} & v \ge 0 \\ 0 & v < 0 \end{cases}$$

- m=Avg. velocity of user
- u=standard Deviation
- k=constant

Thus, in this system model the following assumptions are made:

- The users are uniformly distributed within each area.
- The initial location of each user is defined by *r* and φcoordinates (indirectly x,y coordinates).
- The angles of the direction of movement, θ, are uniformly distributed.
- The users are allowed to move in any direction from the starting location.
- The velocity of each user is constant during the simulation time step.
- The users can freely move between both areas.

Calls from different users are independent.

B. *Simulation Approach*

The simulation is based on a program code developed in MATLAB. It runs for a certain number of iterations as specified by the simulation parameters, which are set at the be-ginning of the simulation.

First, the simulation parameters are set; so the simulation will run according to the specified simulation time and each iteration lasts according to the specified time step. The number of iterations equals to the simulation time divided by the time step.

In each iteration, the mobility of user is set by setting their velocities (magnitude and their direction) of movements. Based on that, the users' locations are updated. Hence, the power of the signal is calculated for each user and compared to a certain predefined threshold. If the power of the signal is less than the predefined threshold; then this means the user should handover to the other area. However, the handover occurs if the power of the signal is less than the predefined threshold and if the user moves towards the next area (in the simulation this is done when the user is at the area border or the direction of movement, θ is within , $0 \leq \theta \leq \pi/2$, or $3\pi/2 \leq \theta \leq 2\pi$).

In the same iteration, the handover delay for each inter working method is calculated. At the end of the simulation, three figures are generated. The first figure illustrates the distribution of users among UMTS-WLAN areas at the beginning of the simulation. The second figure illustrates the number of handovers in UMTS and WLAN areas, which occurred during the simulation. The third figure illustrates the handover delay for each inter working method: the mobile IP method, the gateway method, and the emulator method. The simulation is an interactive tool that interacts with user and enables him to set the parameters and to observe the simulation progress.

C. *Results*

Following are results of simulation:

- Distribution of users: it shows the UMTS coverage area and the WLAN coverage area and the initial users' locations and their distribution among their coverage areas. Each user group is located initially at its own coverage area as shown in Figure 9.
- Number of UMTS-WLAN handover users: It shows the number of users, which performed handover to the other area during each time step. Thus, the number of UMTS hand over users and the number of WLAN handover users are shown in Figure 10.
- Number of UMTS-WLAN dropped users: It shows the number of users, which dropped in each area during each time step. Thus, the number of UMTS dropped users and the number of WLAN dropped users is shown in Figure 11.
- Handover delay: it shows the handover delay for each inter working method: the mobile IP method, the gateway method, and the emulator method as shown in Figure 12.

D. *Discussion*

From the simulation results in the previous section, the performance of inter working methods is clear from Figure 12. The mobile IP method has the highest handover delay, while the gateway method has lower delay and the emulator method has the lowest. This result confirms the expected result that was obtained analytically earlier in section 3. The mobile IP method suffers from high handover delay since the handover occurs between two networks. The usage of the gateway in the gateway method fastens the handover. However, in the emulator method, the handover occurs in the single UMTS network since WLAN is treated as any normal UMTS cell. The used simulation model is not that much accurate but it gives an approximate estimation about the performance of inter working methods. However, some further modification worth to be done in order to get more accurate results but this left as future work.

VI. Conclusions

In this paper, the performance of UMTS-WLAN inter-working methods (the mobile IP method, the gateway method, and the emulator method) has been illustrated analytically and using simulation throughout this paper.

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