VERTICAL HANDOFF BETWEEN UMTS AND WLAN

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ABSTRACT

A major challenge for next generation wireless networks is to use the limited available resources while offering efficiency, capacity and quality of service.
The objective in this work is to review the mobility management issues between two heterogeneous networks namely UMTS and WLAN and to develop techniques that will exploit the advantages of these two networks and integrate them to a solution in such a way that the change is transparent to the user.
A new strategy is proposed for a vertical handoff between the two networks. This strategy minimizes the mean number of handoff and packet loss probability, and improves the throughput.
***Keywords* —** Heterogeneous wireless network, UMTS, WLAN, vertical handoff, ping-pong effect.

1. INTRODUCTION

Nowadays a user has at his disposal a number of possible tools to communicate such as mobile phones, PDA, laptops, and other tools capable of responding to various communication needs.
The diversity of communication needs become cumbersome when a user has to acquire a number of units in order to access his services. Aside from the various services requiring terminals with specific functionalities, the problems stems also from the fact that there exist wireless networks using different technologies.
Furthermore the need for additional bandwidth keeps on increasing as new applications are offered such as video conferencing. Heterogeneous networks using different technologies are developed for various needs and need to interoperate in order to offer continuity in services. This is the case of the following wireless networks such as WiFi, WiMAX, UMTS, Cdma2000 and Satellite. This continuity of service regardless of the network connected to will give autonomy and freedom of mobility to users.
In this article we are considering two particular complementary technologies: UMTS (*Universal Mobile Telecommunications System*) and WLAN (*wireless local area networks*). Their main differences are highlighted in table 1.
In order to navigate between these two technologies in a seamless fashion, some architecture are being considered namely the interconnection architecture « Tight coupling » shown in figure 1.

Table 1 : Main differences between UMTS et WLAN networks.

	UMTS	WLAN
Environment	Outdoor	Indoor
Coverage	big	small
Mobility	big/ limited	limited
Bandwidth	limited	Large
Cost	high	low
QoS real time	Excellent	Inferior
QoS non real time	Inferior	Excellent

The objective is to couple the networks UMTS and WLAN at the SGSN (*Serving GPRS Support Node*) level or the RNC (*Radio Network Controller*) of UMTS that would consider the WLAN network as a simple UMTS cell.

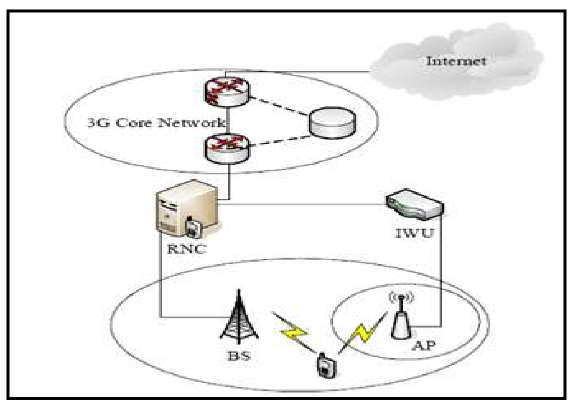

Figure 1: Tight Coupling architecture for interconnection of UMTS/WLAN [1]

The three major issues encountered in this context are: resource reservation, admission control, and the mobility management. The current work concentrates on the mobility management for support of the QoS (Quality of Service) in heterogeneous network UMTS/WLAN.

A mobile terminal needs to have two different interfaces in order to be able to support the services offered by the UMTS et WLAN networks [1] (UMTS interface, WLAN interface). A switching mechanism between the two interfaces is therefore required in case of mobility between the two networks.

2. PROBLEM STATEMENT

As stated, an important issue in this context is the mobility management and the QoS support in UMTS/WLAN network. As the users move from one network to the other the QoS degradation in the mobiles is due to the following elements:

Decrease in throughput: In non real time services (i.e. Data), the mobile terminal may decide at anytime to release the connection with the weaker network during handoff. This action should however not be too hasty. If the mobile terminal keeps on changing too fast and oscillate between the two networks, the decrease in throughput becomes severe and produces a ping-pong effect [2]. The throughput must be maintained during handoff in order to support the users applications performance [3].
Service interruption: In real time services (i.e. VoD), a service interruption can automatically generate a high blockage rate (Call Block Rate) as well as packet loss (Packet Error Rate).

Energy consumption : Every handoff generates an increase in energy consumption and thus reduces the battery life [4].

Cost: The preferred network between UMTS and WLAN with respect to cost is WLAN [5].
A major challenge in vertical handoff is to setup a strategy that will enable a higher throughput in both networks and will minimize the number of handoffs by avoiding the ping-pong effect.

3. OBJECTIVES

In order to address the above issues, the following objectives have been set up:

1. Development of a vertical handoff algorithm that will switch networks from and to UMTS and WLAN and which will be based on the networks properties.
2. Development of a handoff technique based on SINR in UMTS and WLAN that will offer a better QoS :
    - Maximize the throughput essentially in non real time applications.
    - Minimize occurrence of handoff to regulate the ping-pong effect and service interruption on all real time services.
    - Minimize cost by using as much as possible WLAN network.
    - Save as much as possible battery life.
3. Performance analysis of the proposed vertical handoff technique and comparison with existing methods.

4. MOBILITY MANAGEMENT

The mobility management is essential by its objective to ensure service continuity during handoff.
Traffic flowing in these networks will be real time and non real time services. WLAN is the type of network that has initially been developed for non real time services and is thus better fitted for them. Nonetheless WLAN has evolved to be capable of handling real time traffic efficiently. UMTS is however better suited to handle real time traffic since it is designed mainly for that purpose. These particular features have to be considered in the handoff decision. The point to highlight for instance is to decide at an early stage whether handoff should occur for a non real time application being served in UMTS network to a WLAN. Similarly, a voice application in WLAN would also be subject to these considerations. Cost, signal strength and network status considerations should be important factors in the decision.
Vertical handoff procedure goes through three main phases :

A. Handoff decision :

The decision is first based on the link quality. Vertical handoff can be classified based on the handoff initiator and the process controller:[6-7]

- **Network Controlled Handoff** (NCHO) : This is the typical operator approach used to optimize network resources as well as traffic management that maintains a good QoS. The network would then periodically measure metrics upstream and based on these data decide whether to trigger the handoff process. The advantages of this approach are reduced signalling and the non complex terminal.
- **Mobile Terminal-Controlled Handoff** (MCHO) : This is the most used handoff class. It is the mobile terminal that measures the metrics downstream within its own current cell as well as for adjacent cells. Based on these measures, the terminal decides whether to initiate handoff. The MCHO approach guaranties handoff initiation in optimal time and reduces the complexity of the mobile terminal.
- **Mobile Terminal-Assisted Handoff (**MAHO) : In this approach the network as well as the mobile jointly measure metrics upstream and downstream. The terminal downstream measures are periodically sent to the network. The handoff decision is taken by the network. The advantage of this method is that the decision is based on both upstream and downstream measures that are used to optimize the handoff process.

Figure 2 illustrates these handoff strategies with respect to delay and required information.

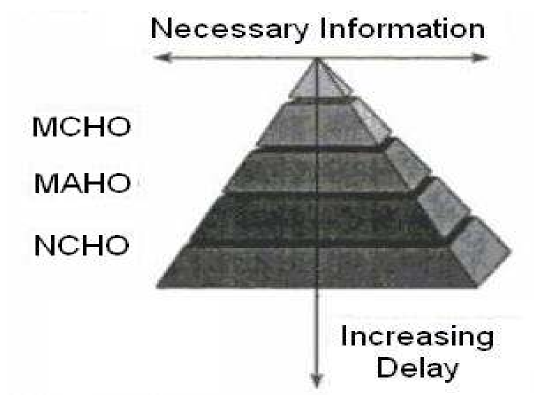

Figure 2 : handoff strategies with respect to delay and required information **[2]**

B. Handoff trigger:

Once handoff decision is made, handoff trigger targets the network and the cell where handoff will take place in order to reserve required resources (channel, frequencies, etc…).

C. Handoff execution :

For handoff execution two main techniques inherent to handoff are considered [8]:

- **Hard Handoff :** The mobile, in this case, first disconnects from the cell it is on and then connects to the target cell.
- **Soft Handoff :** The mobile, in this case, disconnects to the current cell only after being connected to the new target cell.

Figure 3 shows the data flow for hard and soft handoff tehniques.

In figure 3 (a), in the case of hard handoff, there is a blocked period corresponding to the time between the disconnection of the original cell to the connection to the target cell. The extent of this period of time may have a drastic effect on the QoS. In the case of soft handoff in figure 3 (b) there is no such interrupted period. The received data are in fact doubled during the transition [8].

5. RSS, SNR AND SINR ALGORITHMS

5.1 Vertical Handoff based on RSS:

It is the most used traditional algorithm for handoff in cellular networks. The decision to transfer is mainly based on the strength of the signal (RSS: Received Signal Strength) at the edge of the two cells. The mobile triggers the transfer towards the base station (B) that offers a better signal in terms of power (i.e. choose B_{new}, if $RSS_{new} > RSS_{old}$).

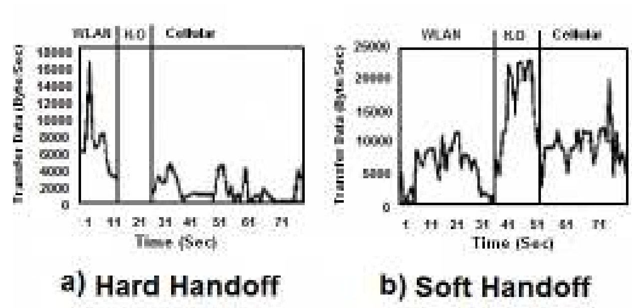

Figure 3 : Throughput for hard (a) and soft handoff (b) **[3].**

Many handoff strategies are defined based on the received signal power metric (RSS) as service availability indicator from an access point. Some if the RSS algorithms proposed in the literature are [9]:

- **RSS:** Handoff is triggered when received signal power of candidate antenna is superior to that of the current antenna ($RSS_{new} > RSS_{old}$).
- **RSS with a theshold :** Handoff is triggered when received signal power of candidate antenna is superior to that of the current antenna and the power of this later is less then a minimum threshold T ($RSS_{new} > RSS_{old}$ and $RSS_{old} < T$).
- **RSS with latency:** Handoff is triggered when received signal power of candidate antenna is superior to that of the current antenna with a predefined margin H ($RSS_{new} > RSS_{old} + H$).
- **Trigger timer**: A timer can be added to any of these algorithms that will start as soon as their conditions are satisfied. Handoff will then start at a predefined moment once the specific conditions are set.

The major inconvenience of the RSS algorithm is the not required number of handoff generated by the weakening of the propagation signal (Path Loss) and the fading of the signal caused by obstacles (shadow fading) as well as multi paths as illustrated in figure 4.

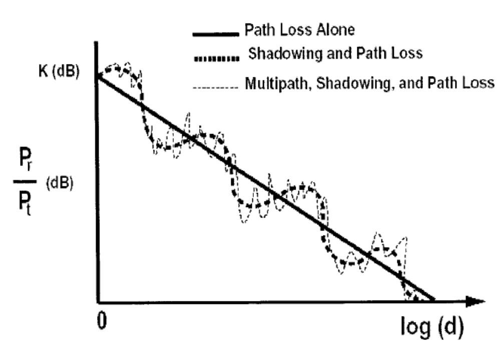

Figure 4: Deterioration of signal as a function of distance [4]

5.2 Vertical Handoff based on SNR:

This vertical handoff is based on the SNR (Signal to Noise Ratio). SNR measures are made at different UMTS and WLAN accesses.
Vertical handoff can then be triggered following a policy similar to that of the RSS such as:

- Handoff is triggered signal to noise ratio of candidate antenna is superior to that of the current antenna: ($SNR_{new} > SNR_{old}$).
- Handoff is triggered when signal to noise ratio of candidate antenna is superior to that of the current antenna and the power of this later is less then a minimum threshold T ($SNR_{new} > SNR_{old}$ and $SNR_{old} < T$).
- Handoff is triggered when signal to noise ratio of candidate antenna is superior to that of the current antenna with a predefined margin H ($SNR_{new} > SNR_{old} + H$).
- Trigger timer similar to RSS but with SNR.

The SNR algorithm is better than the RSS algorithm since the SNR is computed based on RSS and noise characteristics thus giving a more precise evaluation of the received signal.
However on different networks the same SNR could cause different throughputs. A direct comparison of the SNR values will cause a wrong handoff decision. To solve this problem, an adapted SNR could be such as is mentioned in **Chie Ming Chou** and **ChingYao Huang** in their article: "Dynamic Vertical Handover Control Algorithm for WLAN and UMTS" [10] and as shown in figure 5.
A comparison of two SNR values of different networks is made. Based on WLAN graph showing throughput versus SNR, real measures of SNR are made S_{UMTS} and S_{WLAN} for UMTS and WLAN networks respectively. The corresponding throughputs R_{UMTS} and R_{WLAN} are then found.

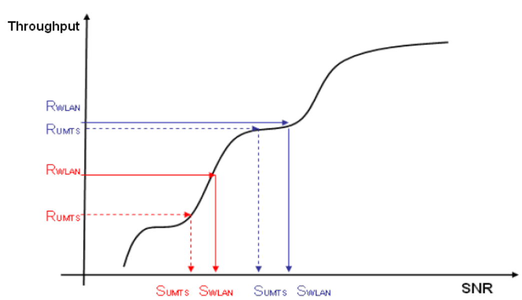

Figure 5: Throughputs with respect to SNR based on WLAN graph [5]

The WLAN performance graph in figure 5 is used to find comparable new adapted SNR values that will serve to take the correct handoff decision [10].

The adapted algorithm based on this technique is powerful and offers good results especially with respect to the number of handoffs. On the other hand, it does not give better results when throughput maximization is concerned because SNR does not allow to obtain the real received values [3].

5.3 Vertical Handoff based on SINR:

To maximize throughput in UMTS/WLAN heterogeneous network, the algorithm based on SINR (Signal to Interference and Noise Ratio) as defined in [3] is most appropriate.
Figure 6 shows the useful signal and the interference signal in UMTS/WLAN heterogeneous network .

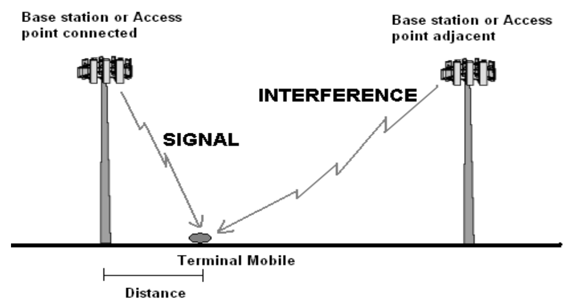

Figure 6: Useful and interference signal

The work of **Kemeng Yang, Iqbal Gondal, Bin Qiu** et **Laurence S. Dooley** presented in the article: "Combined SINR Based Vertical Handoff Algorithm for Next Generation Heterogeneous Wireless Networks" [11] demonstrates the efficiency of the handoff algorithm based on SINR. It is an algorithm that combines many of the following metrics:

1. Received signal strength (RSS)
2. Noise level in the mobile terminal
3. Level of interference received from other adjacent cells that degrade the network throughput.
4. The distance between the mobile terminal and the antenna (base station or access point) being proportional to SINR.

Contrary to the other algorithms RSS and SNR, the algorithm based on SINR can offer a better evaluation of the exact received throughput. This will contribute to the handoff decision.

6. PROPOSED HANDOFF ALGORITHM

The objective aimed is to develop a simple implementation of the proposed solution on mobile terminal and offer a lower handoff delay with the proposed handoff algorithm controlled by the mobile and thus being of the type MCHO (Mobile Terminal controlled Handoff).

6.1 Triggering condition:

Contrary to the presented algorithms based on RSS and SNR, the triggering of the proposed handoff algorithm considers the received SINR in dB with a latency (H) and a timer (ΔT) as presented in (1) and (2) :

For downstream handoff (UMTS to WLAN) :

$$SINR_{WLAN} - SINR_{UMTS} \succ H \quad \text{pour une durée } \Delta T_{aval} \quad (1)$$

For upstream handoff (WLAN to UMTS) :

$$SINR_{WLAN} - SINR_{UMTS} \prec H \quad \text{pour une durée } \Delta T_{amont} \quad (2)$$

With H being the margin defined in dB following the type of service. (real time or non real time).
$\Delta T_{downstream}$, $\Delta T_{upstream}$: Period during which the equations should be verified so to trigger the vertical handoff.
With the use of equations (1) and (2), the algorithm can take the proper decision to handoff attaining higher throughputs downstream as well as minimizing the number of handoff taking place.

6.2 Measure of SINR ratio:

The strategy of the proposed vertical handoff is based on the received SINR ratio (*Signal to Interference Noise Ratio*) of the two different network accesses (UMTS and WLAN) that is the main criteria in the handoff decision.
As described in [3], the received ratio SINR from the two different network is computed as follows:
For UMTS :

$$SINR_{BSj,i} = \frac{G_{BSj,i}P_{BSj}}{P_B + \sum_{k \in BS} (G_{BSk,i}P_{BSk}) - G_{BSj,i}P_{BSj}} \quad (3)$$

with :
P_B : The power of the noise at the terminal level
P_{BSk} : Total power transmitted by the base station BSk
$P_{BSj,i}$: Power transmitted by base station BSj to mobile terminal (i)
$G_{BSj,i}$: Channel gain between the base station BSj and the mobile terminal (i)

For WLAN :

$$SINR_{APj,i} = \frac{G_{APj,i}P_{APj}}{P_B + \sum_{\substack{k \in AP \\ k \neq j}} G_{APk,i}P_{APk}} \quad (4)$$

With:
P_{APj} : The transmit power from access point APj
$G_{APj,i}$: Channel gain between the access point APj and the mobile terminal (i)

As explained previously, the comparison of two metrics of different networks can generate false decisions because of the nature of UMTS and WLAN networks. To avoid this problem, the proposed algorithm is using an adapted SINR based on the performance of the WLAN network.

6.3 Throughputs Estimation :

In order to attain higher throughputs, the handoff algorithm requires an estimate of the received throughput of the two networks. The algorithm uses the Shannon capacity formula. The maximum throughputs can be calculated as a function of bandwidths and the SINR ratios as follows:

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

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

With: R_{WLAN}, $SINR_{WLAN}$ and R_{UMTS}, $SINR_{UMTS}$ the maximum received throughputs and the SINR ratios of WLAN and UMTS networks respectively.
W_{UMTS}, W_{WLAN} : the bandwidths for UMTS and WLAN respectively (W_{WLAN}= 1MHz, W_{UMTS} = 5MHz).
Γ_{UMTS}, Γ_{WLAN} : The QAM coding difference with channel capacity and coding gain for UMTS and WLAN networks (Γ_{UMTS} = 16dB, Γ_{WLAN} = 3dB).

6.4 Latency:

The handoff algorithm must take into consideration the type of service (real time or non real time) to offer a better QoS such as maximizing the throughput in non real time type of service and minimizing the number of handoffs for real time services.
To achieve it, the margin H is dynamically computed in fonction of the type of service as follows:

$$H = \alpha - m \times \left(\frac{R_{WLAN}}{R_{UMTS}} \right)_{dB} + n \times \beta + k \times \left(1 + \frac{\Delta T_{amont}}{\Delta} \right)_{dB} \quad (7)$$

With α and β : coefficients for the magin H ajustement
Non real time service: m=1, n=0.
Real time service : m=0, n=1.
k=0 for downstream handoff (UMTS to WLAN)
k=1 for upstream handoff (WLAN to UMTS).

For non real time service, packets arrive in burst and are not sensible to delays. The user throughput becomes the first metric taken into consideration in the handoff decision. On the other hand, for real time service, packets are sensible to delays. Performance degradation can be caused by handoff delays which should be taken into consideration. In upstream handoff since WLAN has a small coverage, continuous connectivity is taken into consideration in order to guaranty a better QoS.

6.5 Timer:

In addition to the targeted objectives namely higher throughputs, the vertical handoff algorithm must also minimize the number of unnecessary handoffs. The throughput performance is compared before the handoff in avoiding the ping-pong effect. The ping-pong effect is shown in figure 7.
It is assumed that the throughput in both networks is stable. In figure 7 the mobile stays on WLAN for ΔT seconds and looses connection 2Δ seconds. The ΔT is the time duration upon which the decision to trigger the handoff is based and Δ is handoff treatment time (during handoff, no data is acquired).

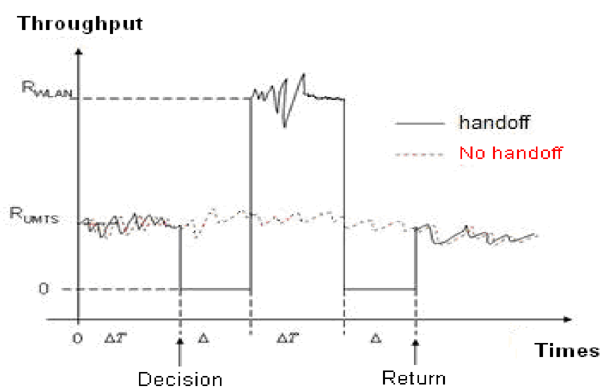

Figure 7: Ping-pong effect **[5]**.

If the duration of ΔT after handoff (during which the throughput is higher) is big enough with respect to the period 2Δ of transition then the handoff is justified. Consequently equation 8 can be verified and obtain the value ΔT.

$$\int_{\Delta+\Delta T}^{\Delta+2\Delta T} R_{WLAN}(t)dt \succ \int_{\Delta T}^{2\Delta+2\Delta T} R_{UMTS}(t)dt \qquad (8)$$

Thus $\Delta T_{downstream}$ and $\Delta T_{upstream}$ that represent the trigger times downstream (UMTS to WLAN) and upstream (WLAN to UMTS) respectively can be calculated as follows:

$$\Delta T_{aval} \geq \frac{2\Delta}{r-1} \quad \text{et} \quad \Delta T_{amont} \geq \frac{2\Delta}{1-\frac{1}{r}} \quad \text{avec } r = \frac{R_{WLAN}}{R_{UMTS}} \qquad (9)$$

With: Δ as the execution time of the handoff and the throughputs R_{WLAN} and R_{UMTS} are assumed stable during this period.
Indeed, the trigger times ΔT ($\Delta T_{downstream}$ or $\Delta T_{upstream}$) are dynamic periods that are computed at each interval based on the new SIMR measures of the two networks.

7. SIMULATION

The simulated mobile is equipped with two interfaces, one to access WLAN IEEE802.11 and the second with UMTS. The degradation of the QoS is evaluated in scenarios with decrease of throughput trying to maintain it at the proper level while reducing loss of packet rate and keeping user application performance. The terminal changes interface according to the proposed handoff algorithm. The default interface is the UMTS cellular interface.

7.1 Model Description:

The simulated environment is outdoors to be as near reality as possible. The model is representing a field 2x2 km into which the terminal moves within a centered square 1x1 km as shown in figure 8.
The simulated field is composed of the following elements :

- 5 UMTS cells covering the entire mobility zone. The radius of a cell is 600 meters.
- 20 WLAN cells distributed randomly on the mobility zone. The radius of a WLAN cell is 200 meters.

The terminal in the mobility model displaces itself randomly in the mobility zone at a fixed speed of 0.5 meters per second corresponding to the average speed of a walking person. Mobile trajectory is random. Figure 9 shows the networks UMTS/WLAN with mobile trajectory.

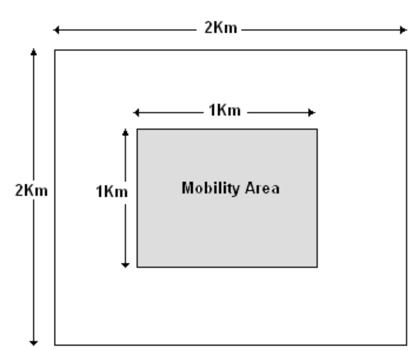

Figure 8 :Simulation field

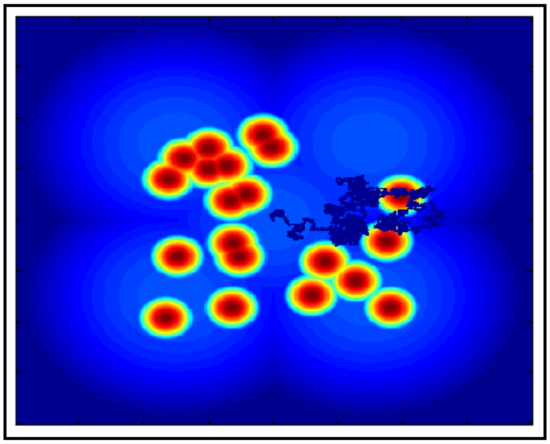

Figure 9 : Map of the heterogeneous network with trajectory

7.2 Propagation Model:

The propagation model used is for outdoor zone with decrease in power:

$$\text{Pathloss} = 32.4 + 20\log(F) + 20\log(D) \qquad (10)$$

With: F the frequency (Mhz), D distance between the terminal and antenna (Km).
The UMTS and WLAN networks simulation parameters are presented in table 2.

Table 2. UMTS and WLAN network parameters

Parameters	UMTS	WLAN
Transmission power	43dBm	30dBm
Transmission Gain	20 dB	2 dB
Reception Gain	2 dB	2 dB
Frequency	2.2Ghz	2.4Ghz
Supplementary attenuation	20 dB	20 dB
sensibility	-100dBm	-100dBm
Bandwidth	5MHz	1MHz

7.3 Traffic Model:

The traffic model used is either real time or non real time type.

- Application for data transfer (non temps réel)
- Application for video transfer (real time) characterized by the following parameters in table 3 :

Table 3. Video application parameters

Parameter	Values
Video flow (BR)	128 kbps
Maximum delay tolerated (D)	50 ms
Video Packet per second (1/T)	25Pps
Acceptable maximum packet lost (B)	4%

7.4 Simulation Metrics :

Each of the metrics calculated for simulations helps verify the studied vertical handoff performance. A high level of noise or interference can have different effect on different algorithm. Four metrics used will help find performance variations between the proposed algorithms and other described algorithms.
The received throughput: This metric is computed for the case of non real time service. The metric determines the bit rate that can be received by the mobile in a given network.
Number of handoff: Détermines the number of handoff taking place between UMTS and WLAN. Ping-pong effects can be detected.
Lost packets: This is a metric computed in the case of real time service giving the number of lost packets in UMTS/WLAN. These loses are caused by weak received throughput or high number of handoffs. The mobile looses packets when the received throughput is less than the flow intensity of video application ($BR>R_{UMTS}$ ou $BR>R_{WLAN}$). When a handoff is executed, the mobile terminal has a dead time (Δ) where the received throughput is null thus loosing packets.
Utilization Rate of each network: The utilization rate of UMTS and WLAN networks determines the cost. WLAN is considered low cost or free of charge with respect to the UMTS network.
The ideal algorithm responds positively to all technical and functional requirements. Table 4 presents the ideal variations of used metrics for this algorithm for increase ▲or for decrease ▼.

Table 4 Sense of variation in the ideal case.

Métrics	**Sense of variation**
Received throughput	▲
Number of handoff	▼
Lost packets	▼
Utilized rate for UMTS	▼
Utilized rate for WLAN	▲

The imagined ideal algorithm should indeed: maximize the received throughput and minimize the number of handoffs and lost packets. This is done while assuring lower cost for minimal use of UMTS and maximun use of WLAN networks.

8. RÉSULS AND DISCUTIONS

Results from RSS, SNR [10] and SINR [11] algorithms are compared with respect to four metrics which are functions of two variables namely the type of service and the handoff delay.

8.1 Non real time Service :

A non real time application scenario is used such as data transfer. Results analyzed are received throughput, number of handoffs, and network utilization rate.

i. Received throughput:

Figure 10 and 11 show the received throughput with respect to time for two algorithms: RSS and the proposed algorithm and the second between the SNR algorithm and the proposed algorithm.

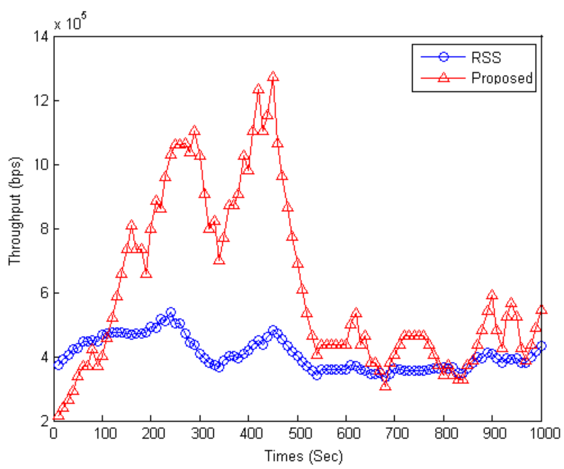

Figure 10 : Received throughput for RSS and proposed algorithm.

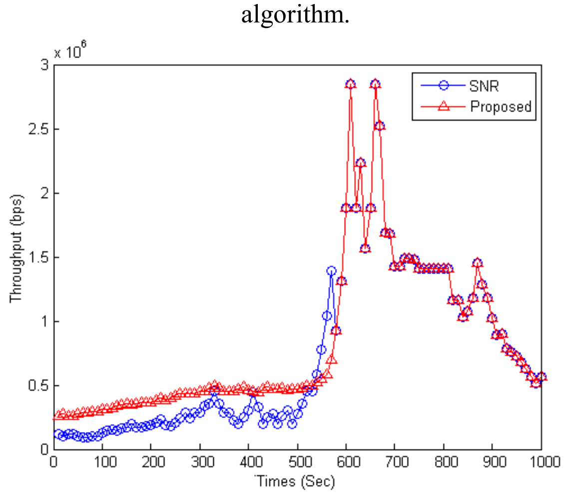

Figure 11 : Received throughput for SNR and proposed algorithm.

In both graphs the proposed algorithm curve is generally positioned above that of RSS and SNR. The proposed algorithm can reach higher throughputs than that with RSS and SNR under the same noise and interference conditions.

Figure 12 presents the average received throughput for each of the algorithms. In figure 12, the SINR algorithm is highest. The proposed algorithm stays close to the SINR results and reaches throughputs higher than for RSS and SNR.

The proposed algorithm uses the same principle than SINR. SINR offers a more exact evaluation of the received throughput to decide on the network to hop in. The throughput maximization is due to noise level and interference considerations for the proposed and SINR algorithm.

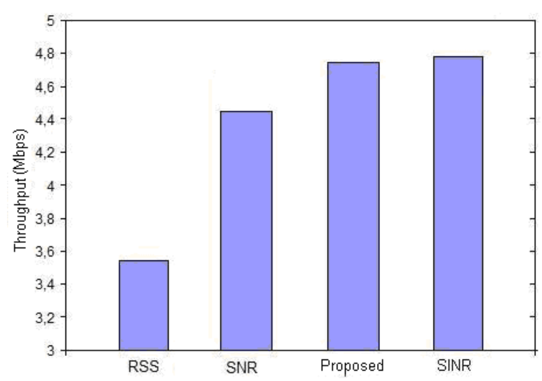

Figure 12 : The average received throughput for each algorithm

The SNR algorithm, in turn, takes into considerations the noise level but not the interference which explains its low received throughput. The traditional RSS algorithm shows the lowest throughput based on its basic principle that neglects the interference levels.

b. Number of Handoffs:

Figure 13 presents results for average number of handoffs for each analysed algorithm.

It is noted that each of the four algorithms has a different number of handoffs. The proposed algorithm shows the best results followed by SNR, RSS and finally SINR.

The proposed algorithm as for SNR avoids the ping-pong effect. RSS and SINR algorithm experience more handoffs by the nature of their need to maximize throughput without considering the number of handoffs taking place.

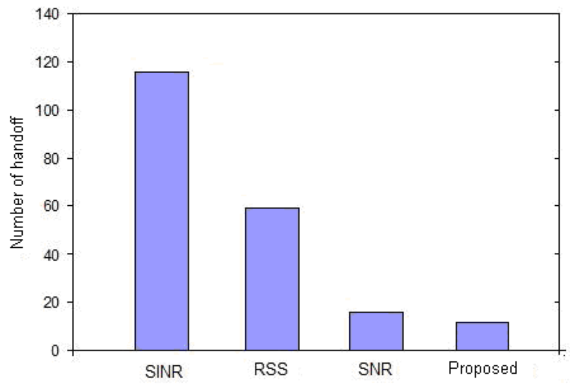

Figure 13 : Average number of handoffs.

c. Utilization rate of networks

The third metric relates to the networks utilization rate and presents the cost in the UMTS/WLAN network. Figure 14 illustrates each network utilization rate for each analyzed algorithm.

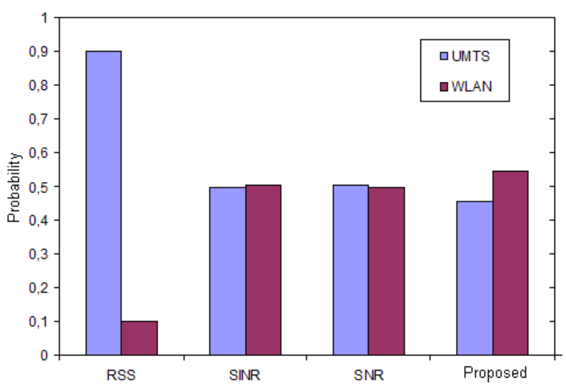

Figure 14 :Probability of UMTS and WLAN utilization

Note that with the proposed algorithm WLAN is used more often and thus minimizes the cost associated to heterogeneous network. With the use of SNR and SINR algorithms the results are similar in terms of network utilization (50% each) with a better cost to that of RSS.

<u>8.2 Real time Service :</u>

For this scenario, real time application is used to transfer video. The following three metrics are analyzed: Lost packets, number of handoffs and networks utilization rate.

i. Lost packets:

Figure 15 and 16 illustrate the number of lost packets comparison for RSS, SINR and the proposed algorithm.

In figure 15 the difference is visible between the two curves. The proposed algorithm minimizes the lost packets with respect to RSS. However, in figures 16 the two curves, showing the proposed algorithm and SINR, are correlated with higher packet losses for the SINR algorithm.

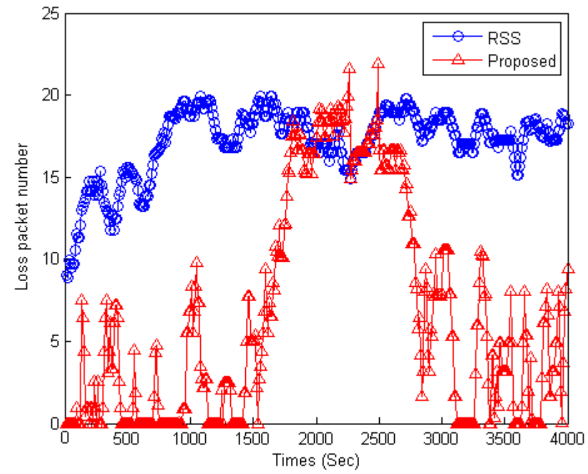

Figure 15 :Lost packets with RSS and proposed algorithm.

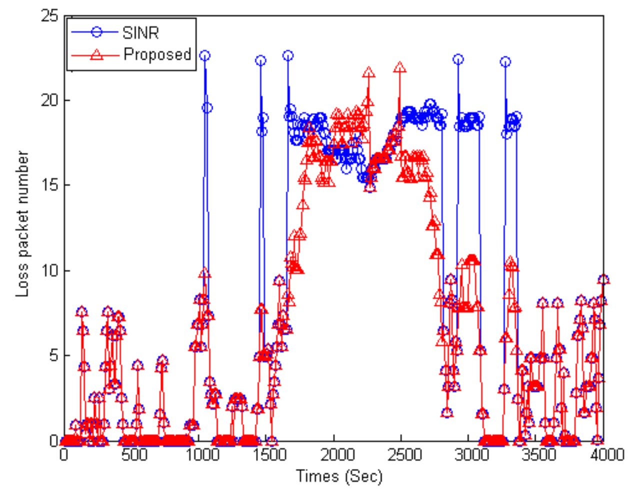

Figure 16 : Lost packets with SINR and proposed algorithm.

Figure 17 presents the average number of packet loss for each of the four analyzed algorithms.

The proposed algorithm generates the lowest average number of lost packets. SNR and SINR show similar average of one packet loss per second. RSS algorithm has a highest packet loss due to the fact that it generate low throughput with respect to the required throughput (BR) for video application as well as the number of handoffs more or less higher where results are exactly the same as in figure 13.

ii Number of Handoff :

Figure 13 presents the average number of handoffs for each of the analyzed algorithms.

The same analysis is applied as in figure 13 which shows the same results for handoff. The proposed algorithm and SNR have similar good results.

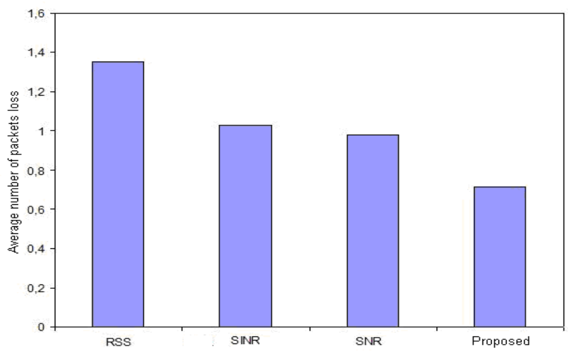

Figure 17 : Average number of packet loss for each algorithm.

iii. Networks utilization rate

It can be seen from figure 18 that the SNR, SINR and proposed algorithm offer good results. Using the WLAN at 60% of the time reduces the cost with respect to RSS which utilizes WLAN only 10% of the time.

From the overall results it is clear that the proposed algorithm offers better performance than other algorithms. This is because it takes into consideration of the noise level and attenuation on the one hand and minimizing the number of handoffs on the other. The four metrics are in fact improved with the proposed algorithm.

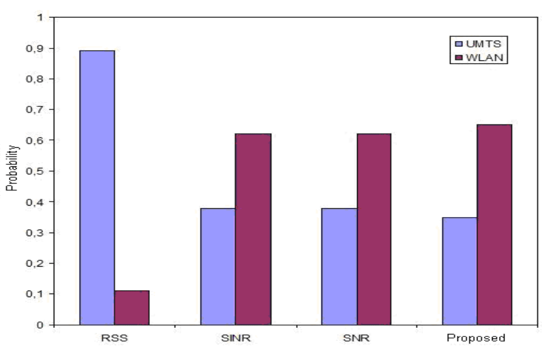

Figure 18 : Probability of utilisation of UMTS and WLAN.

9. CONCLUSION

The proposed vertical handoff algorithm has been simulated and compared to other well known algorithm. Its overall performance was superior in terms of received throughput, number of lost packets, and number of handoffs as well as the cost. It is clear from this study that the noise level and interference have a substantial effect on network performance of each of the analysed algorithm. The proposed algorithm has a better performance because it takes into consideration the noise level and interference. The triggering handoff mechanism used contributes to the reduction of the number of handoffs, loss of packets and maximizes the received throughput.

A recommended further study would be to develop a solution that would tackle the issue of energy consumption. On suggestion would be to activate only one of the interfaces at any time. This is not presently possible since measures must constantly be made on both interfaces.

As a second perspective, a multiuser scenario could be used that would consider the infrastructure and Ad hoc environment. If the network operates in Ad hoc, the mobile terminal can establish a direct connection through neighbour terminals. This would possibly open the development a new distributed handoff mechanism.

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