Innovative Performance Evaluation of Unnecessary Handoffs and Handoff Failures during Access Network Selection between WLAN and Cellular Networks

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ABSTRACT
Received Signal Strength based (RSS) horizontal handoff algorithms have been most commonly used by nearly all second generation and third generation wireless networks in a homogeneous environment. Vertical handoffs or network selection algorithms are the terms coined due to integration and interoperability of existing wired and wireless access networks under the umbrella called as 4G. This work takes a thorough review of existing variations of RSS based network selection through vertical handoff between WLAN and Cellular Networks. It further presents innovative performance analysis of these algorithms in terms of number of handoffs by varying velocity of the Mobile Terminal (MT). Unnecessary handoffs results when the MT traveling at a higher velocity close to the WLAN coverage initiates a handoff to WLAN network resulting in connection breakdown and resource wastage. A handoff failure occurs when the traveling duration inside the WLAN cell is less than the handoff latency from the cellular network to the WLAN. Hence this work further suggests an innovative approach to evaluate the probability of handoff failures and unnecessary handoffs by considering radius of WLAN, velocity of MT and Handoff latencies from Cellular-WLAN.

General Terms
Fourth Generation Networks, Network Selection Algorithm.

Keywords
Vertical Handoff, Received Signal Strength, Threshold, Hysteresis, Handoff Failures, Unnecessary Handoffs.

1. INTRODUCTION
4G networks are envisioned to be a co-existence of various wired and wireless access technologies like Universal Mobile Telecommunication Systems (UMTS), Satellite Systems, Bluetooth, Wireless Local Area Networks (WLAN), Cellular networks, Worldwide interoperability for Microwave Access (WiMax), etc. 4G is not a new technology but it effectively integrates the existing wired and wireless access technology worlds to get the best network coverage and Quality of Service (QoS) for a 4G user. Since the inception of cellular concept, handoffs in homogeneous networks (GSM-GSM, CDMA-CDMA etc) are based on Received Signal Strength (RSS) indicator. Handover, also known as Handoff, is an event taking place whenever one MT moves from one wireless cell to another, abandoning the connection with the first base station and getting attached to the second one. Traditional handoffs are horizontal in nature and occurs between different cells operational under the umbrella of the same technology [2] and vertical handoffs refers to handover among heterogeneous wireless access network technologies. The need for vertical handovers can be initiated for convenience rather than connectivity reasons. Handoff to a new cell takes place when signal strength received by the Mobile Terminal (MT) goes below a specific threshold value and MT detects new Point of Attachment (PoA) with signal strength greater than the current one [5]. Handoff or network selection decisions are very critical for the overall functioning of the 4G networks. The decisions in 4G are vertical in nature as it happens between two completely different networks wherein relative RSS [1,2] cannot be compared directly due to differences in the design of these technologies. But they are very useful in determining the availability and state/condition of different networks. Under the umbrella called as 4G, users get variety of choices in terms of throughput, bandwidth, velocity, mobility, cost, handoff signalling delays, coverage area, location, security etc. These plethora's of options for a vertical handoff decision makes the issue very complicated which necessitates the need of an algorithm which is capable of considering other choices in addition to RSS. Performance analysis of such algorithms in terms of unnecessary handoffs, handoff failures handoff delay, packet loss, throughout etc during actual handoffs decides the usability, merit and applicability of that algorithm in 4G scenario. In the last few years, performance analysis of vertical handoff algorithms has been one of the popular choices among the research community of 4G networks [6, 8].

The paper is organized as follows. Section 2 presents the justification of the work. Section 3 describes relevant related work published by research projects and the academic community. Section 4 details existing mathematical models to improve handoff efficiency. Section 5 briefs different flavours of RSS averaged algorithms and section 6 discusses graphical performance analysis of the algorithms. Finally, section 7 provides concluding remarks and future research directions.

2. MOTIVATION AND JUSTIFICATION OF WORK
This proposal presents an innovative performance evaluation of different variations of RSS based vertical handoff algorithm between WLAN and Cellular Network in a very systematic and simplified manner. The MT moving at a higher speed when

passes through the area close to the WLAN cell boundary, handoffs from Cellular to WLAN are unnecessary [6,7]. These unnecessary handoffs results in connection termination and resource wastage as under such circumstances, MT has a tendency to remain connected to both the access network in order to avoid ping-pong effect. That's why performance analysis of number of unnecessary handoffs and the handoff failure by considering the velocity of MT, radius of WLAN and handover latencies [9,10,13] has been suggested for the given algorithms. The performance analysis is extremely useful in understanding the vertical handoff concept with the help of most basic decision parameter i.e. RSS. This provides a perfect roadmap for the evolution of handoffs from horizontal to vertical. It also proves that RSS-based horizontal handoff concept can be very well extended for vertical handoffs in 4G scenario with some variations. This provides a sound basis to enhance the handoff decision algorithm criteria with parameters such as velocity, bandwidth, cost etc. The simulation scenario, mathematical models and graphical results has been presented in a very explicit and simplified manner so that it can be used as an experiment to help students understand the 4G through vertical handoff perspective.

3. REVIEW OF RELEVANT WORK

Analytical model to analyze horizontal handoffs using absolute and relative signal strength measurements [1] and in a log-normal fading environment [2] are landmark papers based on handoff concepts. Sensitivity of handoff algorithms to propagation environment is presented in [3]. [4] Presents comprehensive conventional trends and classifications of horizontal handoffs. Evaluation framework for vertical handoffs using RSS samples and Windowing technique and WLAN availability duration has been proposed in [5]. The framework discussed in [4] has been thoroughly investigated in terms of signalling load, available bandwidth and packet delay. The work presented by [6] is basically to overcome ping-pong effect by implementing variations of RSS-based methods. A Performance evaluation of vertical handoff between WLAN and Cellular networks [8, 12] is done based on averaged RSS and RSS averaged with Lifetime estimation (LTE). The extension of this work is given in [13]. A method for optimization of vertical handover parameters such as probability of handover failure and unnecessary handovers [10, 13] in fixed Received Signal Strength (RSS) is proposed and implemented. Overview of Vertical Handover strategies [11] in a 4G heterogeneous environment presents a perfect

roadmap and evolution of RSS based handoffs from horizontal to vertical in a 4G scenario [11].

4. COMPUTATIONS OF RSS AND TRAVELING TIME DURATION IN WLAN

The section discusses mathematical models [6, 7, 8, 12] to establish the relation between RSS and distance of MT with Access Point (AP), to average the RSS samples using windowing technique and to estimate the travel duration of a MT in WLAN environment for the simulation scenario shown in Fig. 1.

The scenario includes two cases, namely, MT_{in} and MT_{out} to describe the movement of MT in and out of the WLAN coverage area. MT_{in} is the state when the MT enters WLAN coverage from the cellular network initiating a handoff to WLAN and MT_{out} is when MT enters cellular network leaving WLAN. Handoff decisions are based on Threshold and Hysteresis values for MT_{in}Th (when MT moves in) from Cellular-WLAN and MT_{out}Hys (when MT moves out) from WLAN-Cellular.

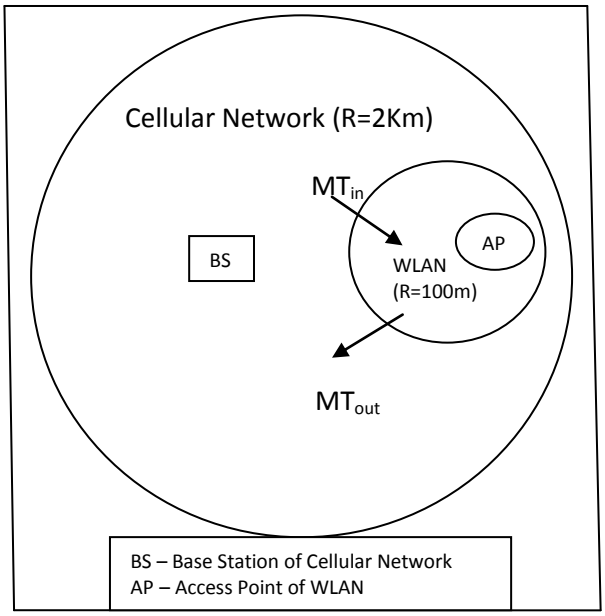

Fig 1: Simulation Scenario

4.1 RSS Computations - Windowing

The channel propagation environment within the WLAN coverage area is modelled using a Log-Linear Path Loss Model (P_L) with shadow fading.

$$P_L(dB) = E_L + 10\,\beta\log_{10}(d) + X_\sigma \quad (1)$$

Where,
E_L = Power Loss (constant)
β = Path Loss exponent (value is 2- 4)
d = Distance between MT and AP

X_σ = Shadow fading modeled as Gaussian with a mean of zero and
standard deviation σ in dB (6 to 12 dB)

By using the Log-Linear Path Loss Model [4], the relation between RSS (dBm) and the distance between MT and AP at any point within the WLAN coverage area is given by

$$RSS = P_{Tx} - E_L - 10\beta\log_{10}(d) + X_\sigma \quad (2)$$

Where,
RSS = Received Signal strength at MT
P_{Tx} = Transmit Power of AP (dBm)

A sliding window with the size of N data elements is defined and using a window with the size of N RSS samples, the measured RSS samples are averaged before they are used to trigger the handoff algorithm [6, 7, 8, 12]

$$RSS_{avg}(m) = \frac{1}{N_w}\sum_{i=0}^{N-1} RSS(-i)W_i \quad (3)$$

where RSS(m) is the RSS of the mth sample after averaging, W_i is the weight assigned to the sample taken at the end of the $(m - i)^{th}$ interval and is equal to 1 for all n as equal weight is assigned to all the previous samples in the averaging rectangular window.

4.2 WLAN Estimation (EST_{wlan})

WLAN estimation [6, 7, 8, 12] is the term used to estimate how long the MT will stay connected to WLAN. RSS computations alongwith EST_{wlan} parameter further improves the handoff decisions and efficiency. This estimation is based on the application based signal strength (δ) parameter which is a combination of bit error rate of channel, application error resilience and QoS requirements of an application. Threshold value of application based signal strength parameter, δ is incorporated in the vertical handoff decision algorithm as follows.

The rate of change of RSS within discrete time interval m_1 and m_2 can be used to estimate the slope as

$$E_S(m) = \frac{RSS_{avg}(m_2) - RSS_{avg}(m_1)}{(m_2 - m_1)} \quad (4)$$

WLAN Estimation, EST_{wlan}, can be calculated using the equation,

$$\boldsymbol{EST_{wlan}[m]} = \frac{\overline{\boldsymbol{RSS}[\boldsymbol{m}]} - \square}{\boldsymbol{E_S}[\boldsymbol{m}]} \quad (5)$$

Where δ is the threshold value (ASST) in the WLAN system.

When the decision to handoff takes place, RSS from various point of attachment (PoA) is compared based on the measured and estimated parameters. The MT will initiate the handoff entering cellular network leaving WLAN. MT_{out} handoff at time m happens if the RSS(m) is less than or equal to a predefined MT_{out} threshold and the EST_{wlan} is less than or equal to the handoff delay threshold, T_{HO}. The first condition is important as it prevents unnecessary handoffs in the WLAN boundary coverage area emanating out of short EST_{wlan} estimate. T_{HO} is set as per the expected handoff delay between the PoAs of the different access technologies. This delay is nothing but the additions of different signaling delay components during various phases of handoffs such as network discovery, network selection, authentication and registration. Delay varies as per the approach (Mobile-IP or end-to-end) adopted for mobility management.

4.3 Handoff Failures and Unnecessary Handoffs

The probability of handoff failures $P(HO)_f$ and unnecessary handoffs $P(HO)_u$ [10] during execution of the above mentioned handoff algorithms has been modelled and analyzed graphically with following assumptions [10]:

- $P(HO)_f$ and $P(HO)_u$ are 0.02 and 0.04, respectively.
- v is velocity of MT
- WLAN Coverage radius, R = 50m
- Handover latencies $_{THO}$ from cellular-WLAN and WLAN-cellular, $t_1 = t_2 = 1$sec

Probability of handoff failures $P(HO)_f$ and Unnecessary Handoffs $P(HO)_u$ [10,13] is given by

$$P(HO)_f = 1, \quad \text{for } vt_1 > 2R \quad (6)$$

$$P(HO)_f = \frac{2}{\pi}\sin^{-1}\left(\frac{vt1}{2R}\right), \quad \text{for } 0 \le vt_1 \le 2R \quad (7)$$

$$P(HO)_u = 1, \quad \text{for } v\,(t_1 + t_2) > 2R \quad (8)$$

$$P(HO)_u = \frac{2}{\pi}\left[\sin^{-1}\left(\frac{(t_1 + t_2)}{2R}\right)\right], 0(t_1 + t_2) \le 2R \quad (9)$$

5. RSS BASED NETWORK SELECTION THROUGH VERTICAL ALGORITHMS

This section presents algorithms which are based on mathematical models of signal strength measurements and Probability of handoff failures and unnecessary handoffs as discussed in the previous section. They are listed as below:

RSS Averaged

- Algorithm 1: RSS_{avg} with Threshold
- Algorithm 2: RSS_{avg} with Threshold plus Hysteresis

RSS Averaged with WLAN Estimation (EST_{wlan})

- Algorith3: RSS_{avg} with EST_{wlan} and Threshold
- Algorith4: RSS_{avg} with EST_{wlan} and Threshold plus Hysteresis

5.1 Algorithm 1: RSS_{avg} with Threshold

Handoff takes place if the RSS received from the neighboring network RSS_{neigh} is higher than the serving network RSS_{serv} and RSS_{serv} is less than a pre-defined threshold T_H.

$$(RSS_{neigh} > RSS_{serv} \text{ and } RSS_{serv} < T) \quad (10)$$

- Calculate the RSS_{serv} of MT in WLAN coverage.
- Calculate the averaged RSS (RSS_{avg}) using equation (3).
- Define the threshold values T_H.
- For MT_{out} scenario
  If (RSS_{avg} (m) < T_H)
  (‘Execute Handoff to cellular')
  else
  if (RSS_{avg}(m) > T_H)
  (‘Stay back in WLAN')
- For MT_{in} scenario
  If (RSS_{avg}(m) > T_H)
  (‘Execute handoff to WLAN);
  else
  (‘Stay back in cellular');
  End

5.2 Algorithm 2: RSS_{avg} with Threshold plus Hysteresis

- Calculate the RSS_{serv} of MT in WLAN coverage.
- Calculate the averaged RSS (RSS_{avg}) using equation (3).
- Define the threshold values MT_{in}Th and MT_{out}Hys for WLAN network.
- For MT_{out} scenario
  if (RSS_{avg} (m) < MT_{out}Hys)
  (‘Execute Handoff to cellular')
  else
  (‘Stay back in WLAN')
  End
- For MT_{in} scenario
  if (RSS_{avg} (m) > MT_{in}Th)
  (‘Execute Handoff to WLAN)
  else
  (‘Stay back in cellular');

5.3 Algorithm 3: RSS_{avg} with EST_{wlan} and Threshold

- Calculate the RSS_{serv} of MT in WLAN coverage.
- Calculate the averaged RSS (RSS_{avg}) using equation (3).
- Calculate the RSS rate of change $E_S(m)$ using equation (4).
- Calculate EST_{wlan} using equation (5).
- Compare RSS_{avg} with predefined threshold (T_H) in WLAN and EST_{wlan} with handoff delay (T_{HO}).
- If $RSS_{avg} < T_H$ && $EST_{wlan} < T_{HO}$ then
  ('Execute handoff to Cellular')
  else
  ('Stay back in WLAN).

5.4 Algorithm 4: RSS Averaged with WLAN Estimation (EST_{wlan}), Threshold plus Hysteresis

- Calculate the RSS_{serv} of MT in WLAN coverage.
- Calculate the averaged RSS (RSS_{avg}) using equation (3).
- Calculate the RSS rate of change $E_S(m)$ using equation (4).
- Calculate EST_{wlan} using equation (5).
- Compare RSS_{avg} with predefined threshold $MT_{out}Hys$ in WLAN and EST_{wlan} with handoff delay (T_{HO}).
- If $RSS_{avg} < MT_{out}Hys$ && $EST_{wlan} < T_{HO}$
  then
  ('Execute handoff to Cellular')
  else
  ('Stay back in WLAN)..

6. SIMULATION VALIDATION

The scenario in Fig. 1 shows the integration of Cellular network and WLAN. Coverage area of cellular provides better availability to MT compared to WLAN but it gives lesser throughput of just 2 Mbps as compared to WLAN (54 Mbps). MT would always opt for higher bandwidth for different applications and will try to use WLAN only. This section analyzes the performance of this during handoffs. Fig. 4 shows the comparative performance of all four algorithms in terms of number of unnecessary handoffs by varying velocity of a MT.

Algorithm 2 using two thresholds (Hysteresis + Threshold) gives less number of handoffs compared to Algorithm 1 using only one threshold. This margin of threshold (hysteresis) provides the better decision capability to the algorithm. RSS_{avg} with Hysteresis plus Threshold reduces number of unnecessary handoffs considerably as compared to RSS_{avg} with a threshold. Algorithm 2 using only RSS_{avg} gives the more number of handoffs than the Algorithm 4 using RSS_{avg} along EST_{wlan}. It also justifies the importance of EST_{wlan} with two thresholds.

Fig. 2 shows the summary of comparative performance of all criterion used for handoff decision. This clearly shows that vertical handoff based on RSS averaged with EST_{wlan} considering two thresholds (Hysteresis) gives the best results amongst all the four criterions discussed by literally clamping the number of unnecessary handoffs to 1 at a higher velocity of MT. Graphical results in Fig. 3 and Fig. 4 demonstrate a linear relationship between speed of MT and handoff failure probability and probability of unnecessary handoffs using fixed value of RSS. The results are obtained by using equation 7 & equation 9. This relationship is applicable to all four variations of the algorithm. The result shown in Fig. 4 re-enforces that there is a linear relationship between number of unnecessary handoffs, handoff failures with the velocity of MT.

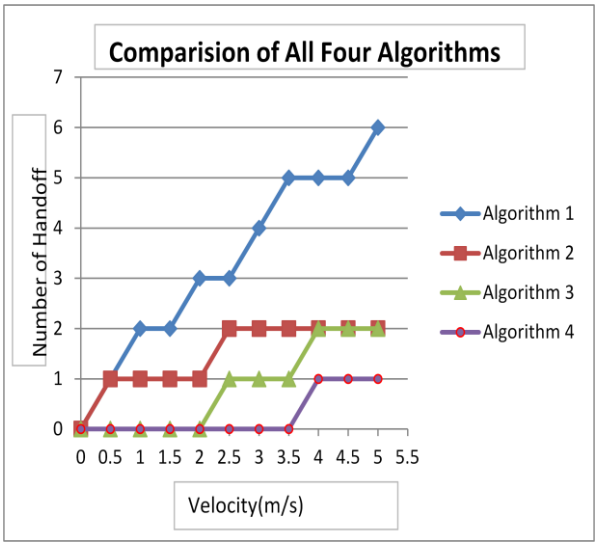

Fig 2: Comparisons of all 4 algorithms

Therefore, the handoff from cellular to WLAN is to be avoided when the MT is moving with higher velocity or handoff should happen to WLAN of larger coverage area. If some high value time threshold parameter based on the traveling distance of the MT within the WLAN cell is calculated then lower values of handoff failure and unnecessary handoffs can be achieved by providing an uninterrupted service to the users.

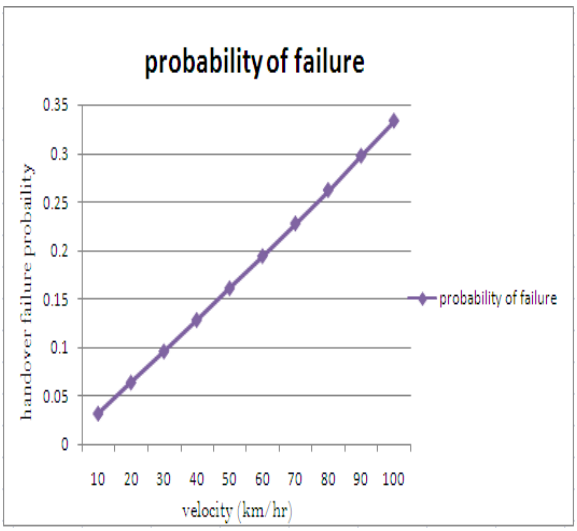

Fig 3: Probability of handover failures

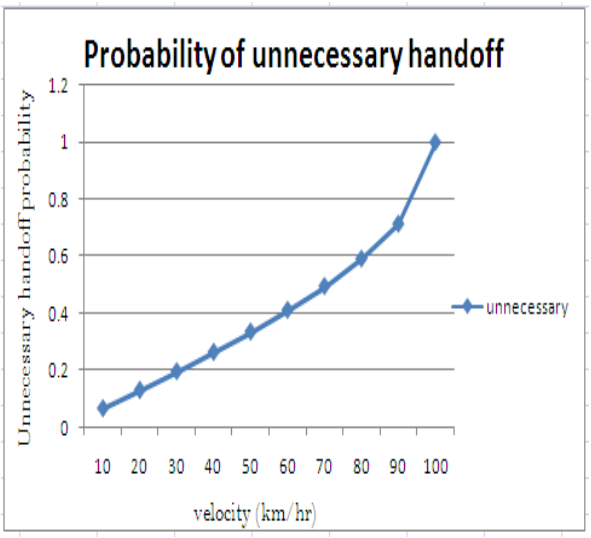

Fig 4: Probability of unnecessary handovers

7. CONCLUDING REMARKS

This paper considers RSS as the basic criterion for vertical handoff decision. RSS is a function of distance of MT from the AP/BS and it decreases as the MT goes away from it. Path loss increases with increase in distance and RSS is obtained by deducting all the losses from the transmitted power of AP/BS. The tendency of the MT to leave the AP coverage increases as the velocity of MT increases.

A drastic increase in the number of handoffs is observed when algorithm works with only one threshold value as compared to the two distinct thresholds for moving in and moving out scenarios of WLAN. Analysis of the graphical results clearly indicates that network selection which is based on RSS averaged with WLAN Estimation (EST_{wlan}) considering two thresholds gives the best results amongst all the four criterions discussed. That proves that RSS is the necessary but not sufficient criteria for vertical handoff decisions.

Future Research Directions

- To add more number of WLAN cells in the BS coverage area.
- To integrate different types of networks like UMTS, WiMAX, and Bluetooth to provide high data rate.
- Handoff decision to include more number of criteria like signal to noise ratio, carrier to interference ratio, bandwidth, location, traveling distance, monitory cost etc. along with RSS for decision making.
- To design a system to keep the lower handoff failure probability and unnecessary handoffs probability irrespective of the speed of the MT.

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