Seamless Vertical Handover in WiFi and WiMAX Networks using RSS and Motion Detection: An Investigation.

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ABSTRACT

In this paper, we propose a decision making algorithm for seamless vertical handover between WiFi hotspots and an overlay WiMAX network. The inputs to the algorithm are the WiFi received signal strength (RSS) and estimated end-to-end TCP handover latency. Simulation of the algorithm using Matlab® reveals that the distance from the WiFi reception boundary at which handover must be initiated if it is to be seamless increases with both end-to-end TCP/IP handover latency and the speed of the mobile terminal towards or away from the WiFi access point. We conclude that RSS-based seamless handovers need to be augmented with network layer information if they are to be optimal.

(Keywords: WiFi, WiMAX, horizontal handover, vertical handover, seamless vertical handover, heterogeneous wireless networks, wireless overlay networks)

INTRODUCTION

The Internet is increasingly becoming the sole platform for accessing network services such as telephony, data, and the World Wide Web. Users now expect Internet connectivity wherever they are, be it at home, at work, or in transit between any two locations. Fourth generation (4G) networks with capabilities to enable users to do so are currently being investigated and tested. Such networks will enable users to stay connected to the Internet even as they move through different underlying networks. Examples of underlying networks include WiFi [1][2], WiMAX [3][4], and GSM [5].

The process of connecting a mobile user to a new network access node and disconnecting from the node to which it is currently connected is called handover (or handoff) [6]. The process is called horizontal handover if the access nodes are from the same network; otherwise it is called vertical handover. Ideally, handover should occur seamlessly, without the user being aware that he/she has crossed a network boundary.

The vertical handover process is a three-stage process and takes a finite amount of time to complete [7]. The first stage is the network discovery stage where the user's mobile device identifies all the possible underlying networks it can use to access the Internet. This is followed by the handover decision stage, where the mobile device selects the network to switch to and the time to do so. The last stage is the handover execution stage when the mobile device switches over from its current network to the other network. For handover to be seamless, all these stages have to be completed prior to the mobile terminal leaving the coverage area of the access point to which it is currently connected to, otherwise the connection is dropped.

In this paper we propose a decision making algorithm for seamless vertical handover between WiFi hotspots and an overlay WiMAX network. WiFi provides broadband connectivity for LANs, whereas the WiMAX network provides metropolitan area broadband coverage with guaranteed quality of service. WiFi hotspots typically offer free access to bona fide users whilst WiMAX overlay networks provide user access for a fee. It is therefore necessary to provide WiFi connectivity for as long as possible and only allow a roaming mobile device to switch over to an overlay WiMAX network when the WiFi services gets out of range or when its quality of service becomes unacceptable.

The inputs to the decision making algorithm are the WiFi received signal strength (RSS) and estimated end-to-end TCP handover latency (i.e., the estimated time lapse between the initiation and completion of WiFi and WiMAX handover for Internet connectivity). The algorithm assumes an overlay WiMAX network, meaning that WiMAX coverage is assumed to be always available and the mobile terminal has to switch to and fro WiFi depending on the availability of WiFi hotspots.

BACKGROUND

Handover is facilitated by measuring radio parameters such as RSS, path loss, interference, and bit error rate (BER), separately or in combination. In homogeneous wireless networks, RSS is the main factor in making handover decisions. For instance, in WiFi 802.11b networks a mobile terminal compares the difference between the RSS of two or more access points and initiates a link layer handover to the access point with the highest RSS [8].

For heterogeneous wireless networks with different characteristics, several other factors such as quality of service, monetary cost, network conditions, system performance, mobile node conditions, etc. have to be taken into account as well [9]. Unlike RSS measurements which can be evaluated at the physical and medium access (MAC) layers, such factors are best implemented at higher layers (i.e., layer 2 and layer 3) of the OSI network stack [10]. In this paper we combine RSS and the speed of a mobile terminal with respect to a WiFi access point to come up with a seamless handover decision making algorithm. In the overlay network we envisage, a mobile terminal will monitor the WiFi RSS and initiate a handover to the overlay WiMAX network when the WiFi RSS goes below a specified threshold level.

For handover to be seamless in a network with moving terminals, the decision to initiate handover should be taken before the user moves out of the coverage area of its current access point. The faster the user is moving away from the access point, the earlier the handover has to be initiated. For instance, Lee et al. [9] have proposed a movement-aware vertical handover algorithm between WiFi and WiMAX which incorporates the velocity and location of a mobile terminal, in addition to RSS measurements, to make handover decisions. Chen et al. [11], also

incorporate mobile position and velocity to arrive at a handover decision. Unlike [9], they obtain all the required variables using RSS measurements only. This is accomplished by estimating the mobile terminal's position, speed, and direction of motion and by carrying out a trend analysis of current and previous RSS measurement values.

Despite the proliferation of RSS-based seamless vertical handover algorithms, there appears to be little research regarding their performance in practical operational settings. In an IP network overlaid on heterogeneous wireless networks, the handover process comprising the network discovery stage, decision making stage and handover execution stage, the total handover latency can be as 1290 ms [12]. Our paper seeks to address this gap in research by analyzing the latencies introduced by a basic RSS-based seamless vertical handover algorithm that takes into account the velocity of a mobile terminal and its position from the boundary of a WiFi access point coverage area.

METHOD SECTION

We now describe the algorithm we used to investigate the effect of end-to-end TCP handover latency and mobile terminal velocity on the minimum distance from the WiFi reception boundary at which handoff must be initiated if it is to be seamless. Figure 1 shows the computational steps implemented when a mobile terminal is approaching and when it is moving away from a WiFi access point. In both cases, samples of the WiFi RSS are measured at regular time intervals and a moving average value (MRSS) is computed for each RSS sample.

We first consider the case when the mobile terminal is approaching the WiFi access point. If the computed value of MRSS is less or equal to the receiver sensitivity R_{th} it means that the mobile terminal has already left the WiFi reception area. In this case handover from WiFi to WiMAX is immediately initiated. If, on the other hand, the MRSS value exceeds the receiver sensitivity, the current position and velocity of the mobile are computed. These two values are used to determine the amount of time remaining before the mobile terminal crosses the WiFi reception boundary. If this time exceeds the specified end-to-end TCP handover latency, a make-before-break routine initiated to ensure seamless handover to the WiMAX network. A make-before-

break handover routine has been adopted to ensure that connectivity to the Internet is maintained throughout the handover process.

We then consider the case when the mobile terminal is moving away from the WiFi access point. If the computed value of MRSS is greater or equal to the receiver sensitivity R_{th} it means that the mobile terminal is already in the WiFi reception area. In this case handover from WiMAX to WiFi is immediately initiated. If, on the other hand, the MRSS value is less than the receiver sensitivity, the current position and velocity of the mobile are computed. These two values are used to determine the amount of time remaining before the mobile terminal crosses into the WiFi reception area. If this time exceeds the specified end-to-end TCP handover latency, a make-before-break handover routine to the WiFi network is initiated. The make-before-break handover routine guarantees connectivity to the Internet through the WiFi network as soon as the mobile terminal reaches the boundary of its reception area. This ensures that the mobile terminal maximizes connectivity via the WiFi network.
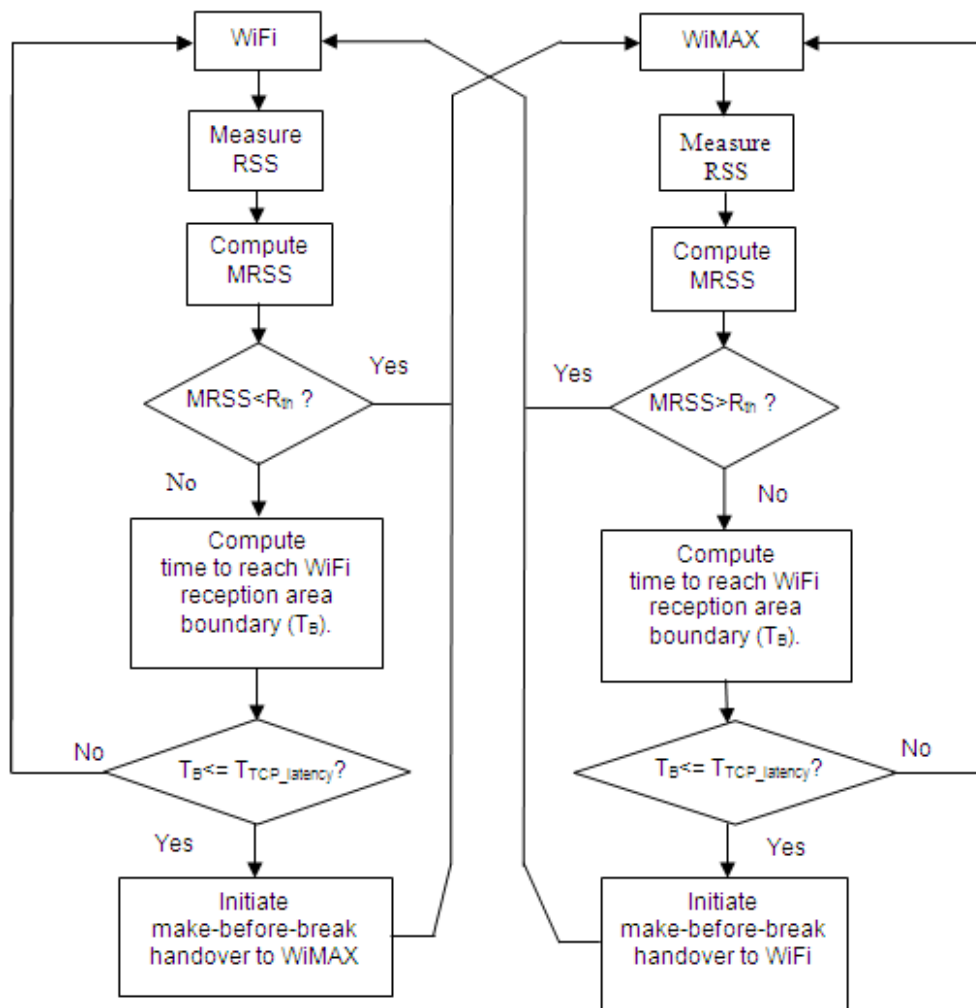

Figure 1: A Flow Chart showing the Proposed RSS-Based Seamless Vertical Handover Algorithm.

EXPERIMENTS, RESULTS, AND DISCUSSION

The seamless handover algorithm was evaluated for both the case when a mobile terminal is approaching a WiFi access point, and when it is moving away from the access point. In each case simulations were carried out for typical speeds the mobile terminal is likely to experience in the UK, as shown in Table 1. The typical latency for handover between WiFi and WiMAX for an end-to-end TCP connection ranges from 450ms to 1 second [13].

Table 1: Typical Speeds for UK Mobile Handsets.

Motion Scenario	Speed (mph)	Speed (m/s)
Walking person	2.5	1.2
City car speed limit	20	10
Motorway speed limit	70	30
Peri-urban maximum train speed	125.00	55.88
Interurban maximum speed train	200	89.41

Experimental Method

The distance from the WiFi reception limit at which the handoff process commenced was recorded for handoff latencies ranging from 100ms to 1100ms. This distance was the minimum possible distance, as determined by our algorithm, for handoff to take place seamlessly. The maximum reception distance from the WiFi access point is obtained using the path loss equation:

$$Ploss_{dB} = 20\log_{10}(4\pi/\lambda) + 10\rho \log_{10}d \qquad (1)$$

where $Ploss_{dB}$ is the signal loss in dB between the transmitter and receiver; λ is the wavelength of the WiFi signal; ρ is the path loss constant, and d is the distance between the between the transmitter and receiver.

The maximum reception distance for WiFi reception occurs when the path loss, as computed by Equation 1 above equals the difference between the transmit power and the receiver sensitivity. Following [14] we have used a WiFi transmit power of +17dBm, an outdoor path loss factor of 2 and a receiver sensitivity of -76dBm. Substituting these values into Equation 1

gives a maximum reception distance of 994 metres.

Results

Figure 2 and Figure 3 show the relationship between handover initiation distance and latency for the case when the mobile terminal is approaching the WiFi access point, and when it is moving away.
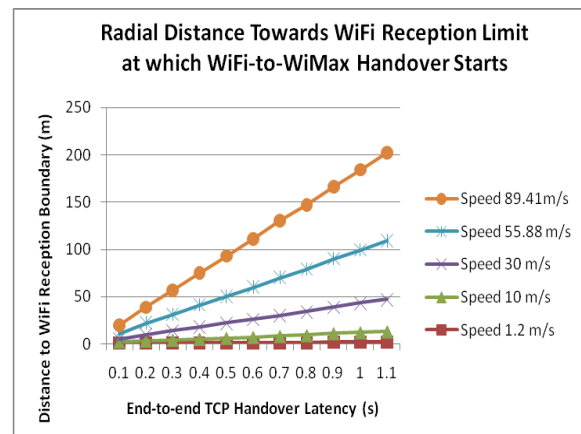

Figure 2: Plot of Handover Initiation Distance against Latency for the Case when the Mobile Terminal is approaching the WiFi Access Point.
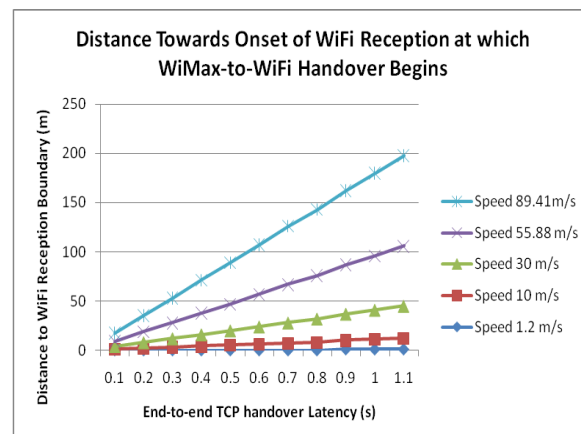

Figure 3: Plot of Handover Initiation Distance against Latency for the Case when the Mobile Terminal is moving away from the WiFi Access Point.

The two figures show that the distance at which handover must be initiated increases with both end-to-end TCP/IP handover latency and the speed of the mobile terminal relative to the WiFi access point. For a typical walking speed (1.2 m/s), handover is initiated almost at the WiFi reception boundary for all values of end-to-end TCP/IP handover latency.

When the mobile terminal speed is increased to the UK inner city maximum car speed limit of 20 miles per hour (10 m/s), it is found that the distance from the WiFi reception boundary at which handoff is initiated increases from 1 meter (for a handover latency of 100 ms) to 11 meters (for a handover latency of 1100 ms). For a mobile terminal travelling at the UK maximum motorway speed limit of 70 miles per hour (30 m/s), the calculated distances increase from 3 meters (for a handover latency of 100 ms) to 34 meters (for a handover latency of 100 ms), and from 6 meters to 62 meters for a peri-urban train speed of 125 miles per hour and from 9 meters to 93 meters for a high train speed of 200 miles per hour.

Implications of the Results

As can be seen from the experimental analysis, and illustrated in Figure 4, the mobile terminal is simultaneously connected to both the WiFi and WiMAX network for some distance on either side of the boundary of the WiFi coverage area. This is because of the need initiate handover prior to reaching the boundary of WiFi coverage for both the case when the mobile terminal is approaching or leaving the WiFi coverage area.

This overlap distance depends on both the speed of the mobile terminal and the expected end-to-end TCP/IP handover latency. Consequently, the power consumption of the mobile terminal is likely to increase when it is traversing this overlap area since both the WiFi and WiMAX transceivers will be operational. Hence, the mobile terminal is likely to consume power simply by traversing WiFi hotspots, whether or not it is in active use. These results therefore suggest that the use of RSS-based seamless vertical handover between heterogeneous wireless networks increases the power consumption of mobile terminals. In addition, since the mobile terminal is connected to the WiMAX network during the overlap region, the user would still face the monetary costs associated with WiMAX access.

Assuming the mobile terminal is approaching a WiFi hotspot, handover has to be initiated prior to reaching the boundary of the WiFi coverage area as determined by the transmission power of the WiFi access terminal and the sensitivity of the WiFi transceiver on board the mobile terminal.

For this to be possible, the handover mechanism of the mobile terminal would need to have a better sensitivity than the WiFi transceiver. In a more practical mobile terminal it would be more appropriate and cost effective to have a single WiFi transceiver for communication as well as for implementing handover. This implies that when the mobile terminal is approaching a WiFi hotspot, handover would be initiated only when the mobile terminal reaches the boundary of the WiFi coverage area. Therefore in this case the region in which WiFi and WiMAX connectivity overlap lies entirely within the WiFi coverage area. Consequently the use of RSS-based seamless vertical handover reduces the area of exclusive WiFi connection by twice the distance at which handover must be initiated if it is to be seamless. Again this distance increases with both the speed of the mobile terminal and the expected end-to-end TCP/IP handover latency.
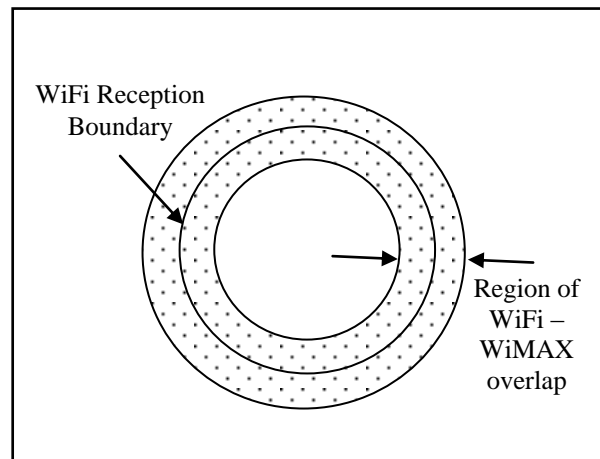

Figure 4: Region of Overlap within and outside a WiFi Hotspot.

CONCLUSION AND FUTURE WORK

The research described in this paper suggests that RSS-based seamless handover algorithms, as typified by the algorithm proposed and evaluated in this paper, are sub-optimal. Such

algorithms create regions of network connection overlap around the boundary of WiFi coverage. This leads to high power consumption by the mobile terminal since it is simultaneously connected to both the WiMAX and WiFi networks. Moreover, since the mobile terminal remains connected to the WiMAX network in the overlap region, it is still subject to network usage billing from the operators of the WiMAX network.

Possible improvements to RSS-based seamless handover algorithms would be to incorporate network layer predictive algorithms. Unlike algorithms based at the physical and link layer, a network layer algorithm has visibility of the two underlying wireless networks as well as the overlying Internet. Hence such algorithms are better placed to anticipate and initiate handover well before it is required. This would include the identification and setting up of both wireless and TCP/IP connections to the next access point prior to the actual handover process.

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