Generic Vertical Handoff Decision Function for Heterogeneous Wireless Networks

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Abstract - **As mobile wireless networks increase in popularity and pervasiveness, we are facing the challenge of integration of diverse wireless networks such as WLANs and WWANs. Consequently, it is becoming progressively more important to arrive at a vertical handoff solution where users can move among various types of networks efficiently and seamlessly. The ability to remain connected as a mobile device roams across different types of networks still remains an unachieved objective. Frequently, just choosing the best network to connect to, is a challenging problem due to the large number of network characteristics that need to be considered. Identifying these decision factors is therefore one of the principal objectives for seamless mobility. In this paper, we discuss the different factors and metric qualities that give an indication of whether or not a handoff is needed. We then describe a vertical handoff decision function, VHDF, which enables devices to assign weights to different network factors such as monetary cost, quality of service, power requirements, personal preference, etc.**

I. INTRODUCTION

The interest in fourth generation (4G) wireless communications is ever-increasing as wireless networks and mobile communications grow at an astonishing rate. 4G promises to provide broader coverage, lower access costs, the convenience of using a single "all-in-one" device, and more dependable wireless access even with the loss or failure of one or more networks. It promises to bring this about by supporting global roaming across heterogeneous wireless and mobile networks: for example, from a wide coverage, low-bandwidth Wireless Wide Area Network (WWAN) to a small coverage, high-bandwidth

Wireless Local Area Network (WLAN). WLAN hotspots (which have recently increased in popularity [1]) offer mobile users high bandwidth wireless internet connectivity in a variety of sites within a city [2]. Despite of this rapid increase in hotspots, wireless internet access remains limited to a small number of geographical areas because of the limited physical coverage of WLANS. On the other hand, despite their lower bandwidth, cellular networks (WWANs) have considerably wider coverage and are therefore much more available. In 4G, a WLAN cell could be overlaid within a cellular network and vertical mobility combines the capacity of local area networks and the coverage of wide area cellular networks [3, 4]. 4G will integrate a multitude of different heterogeneous networks including cellular (1G, 2G and 3G), WLANs, satellite systems, 802.16 and Bluetooth just to mention a few. This transfer between two heterogeneous network interfaces is known as vertical handoff.

Criterion of a vertical handoff is one of the chief challenges for seamless mobility. Traditional handoff detection operations and policies, decision metrics, radio link transfer and channel assignment are not able to acclimatize to dynamic vertical handoff conditions or varying network availabilities. Furthermore, traditional handoff does not allow for device selection of networks since it assumes that there is only one type of network. In a mixed networking environment, user choice is a desirable enhancement.

In this study, we briefly describe the diverse factors and qualities that aid in handoff decision. We then propose a vertical handoff decision function, VHDF, which allows the user to strategically prioritize the different network characteristics such as network performance, user preference and monetary cost. This function is simple and can be easily applied to any vertical handoff approach.

The remainder of this paper is organized as follows. Section II presents our comprehensive study of various handoff decision factors that may well be used in our function. Section III explains and qualitatively evaluates the proposed vertical handoff decision function, VHDF. Finally, conclusions drawn from the paper and future work are discussed in Section IV.

II. VERTICAL HANDOFF DECISION CHARACTERISTICS

Seamless handoff across the different wireless networks is becoming increasingly important [5]. Whereas wired networks regularly grant high bandwidth and consistent access to the Internet, wireless networks make it possible for users to access a variety of services even when they are moving. As a result, seamless handoff, with low delay and minimal packet loss, has become a crucial factor for mobile users who wish to receive continuous and reliable services.

One of the chief issues that aid in providing seamless handoff is the ability to correctly decide whether or not to carryout vertical handoff at any given time. This could be accomplished by taking into consideration two key issues: network conditions for vertical handoff decisions and connection maintenance [6]. These two issues need to be tightly coupled in order to move seamlessly across different network interfaces. To attain positive vertical handoff, the network state ought to be constantly obtainable by means of a suitable handoff metric. In multi-network environments, this is very challenging and hard to achieve as there does not exist a single factor than can provide a clear idea of when to handoff. Signal strength, which is the chief metric measured in traditional horizontal handoffs, cannot be utilized for vertical handoff decisions due to the overlay nature of heterogeneous networks and the different physical techniques used by each network. Thus a natural question arises as to what factors should be considered in the handoff decision. Therefore, after thorough study, the most important decision factors were identified. We explain the significance of each and why they are selected in VHDF.

Cost of Service: The cost of the different services to the user is a major issue, and could sometimes be the decisive factor in the choice of a network. Different broadband Wireless Internet Service Providers (WISPs) and cellular service providers may well provide a variety of billing plans and options that will probably influence the customer's choice of network and thus handoff decision.

Security: Risks are inherent in any wireless technology. Some of these risks are similar to those of wired networks; some are exacerbated by wireless connectivity; some are new. Perhaps the most significant source of risks in wireless networks is that the technology's underlying communications medium, the airwave, is open to intruders, making it the logical equivalent of an Ethernet port in the parking lot [7]. Therefore security was chosen as one of the main factors in the vertical handoff decision function.

Power Requirements: Wireless devices operate on limited battery power. When the level decreases, handing off (or remaining connected) to a network with low power consumption can provide elongated usage time. For instance, if a device's battery is nearly exhausted then handing over from a WLAN to WWAN would be a smart decision. This is due to the fact that when operating in a cellular WWAN, the device is idle for most of the time. However, given the unpredictable and erratic nature of transmissions with WLANs, handsets are unable to standby between packet transmission since there is no set time for the arrival and transmission of data and packets arrive sporadically.

Proactive Handoff: by proactive handoff, the users are involved in the vertical handoff decision and have the final decision on whether or not to handoff, regardless of the network conditions. By permitting the user to choose a preferred network the system is able to accommodate the user's special requirements.

Quality of Service: Handing over to a network with better conditions and higher performance would usually provide improved service levels [8]. Transmission rates, error rates, and other characteristics can be measured in order to decide which network can provide a higher assurance of continuous connectivity.

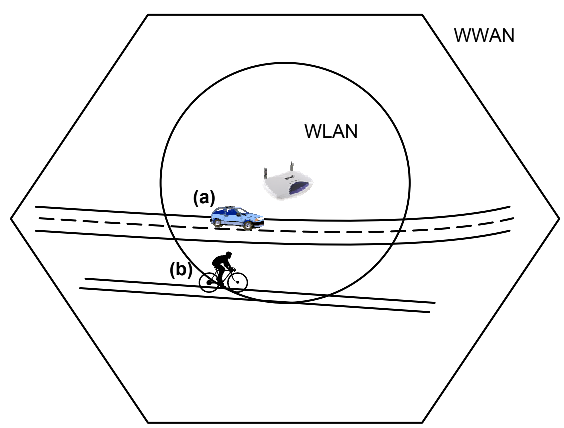

Figure 1: (a) If a user's velocity is high, there is no need for handoff, even if the signal strength is very strong, since the user is mostly likely to leave after a short period of time. (b) Motion and location could indicate that the person might probably promptly leave a network's coverage area. For instance, in this diagram, although the cyclist's velocity is low, he is moving on the edge of the coverage and therefore handoff to the WLAN is discouraged.

Velocity: In vertical handoff, the velocity factor has a larger weight and imperative effect in handoff decision than in traditional horizontal handoffs. Because of the overlaid architecture of heterogeneous networks, handing off to an embedded network when traveling at high speeds is discouraged since a handoff back to the original network would occur very shortly afterwards. Figure 1. shows how measuring velocity could help in preventing redundant vertical handoffs.

Vertical handoff decisions cannot be based on one or a couple of the factors discussed. The majority of these aspects have a momentous effect on the correct network choice. In the next section, the proposed vertical handoff decision function, VHDF, is presented. The abovementioned characteristics are taken into consideration in order to offer seamless vertical handoff across heterogeneous networks.

III. VERTICAL HANDOFF DECISION FUNCTION

In this section we propose a vertical handoff decision function (VHDF).

A. VHDF Description

We argue that the vertical handoff decision is a composition of the following metric attributes: *cost of service (C), power requirements (W), security (S), proactive handoff (user preference) (U), network conditions (N), network performance (P) and velocity (V)*. Note that there may be additional characteristics and qualities that could be included (such as moving patterns [9]); however we believe that these are the key factors for most vertical handoff decisions, regardless of the direction of the vertical handoff. If VHDF is in fact an amalgamation of the abovementioned metrics, subsequently the *network quality (Q)* – which provides a measure of the usability appropriateness of a certain network - could be measured via a function:

$$Q = f(aC, bW, cS, dU, eN, fP, gV), \qquad (1)$$

where *a, b, c, d, e, f, g.* are numerical scores describing the amount and extent of that particular metric in one of the networks and it is assumed that

$$0 \leq a, b, c, d, e, f, g \leq \infty. \qquad (2)$$

The following example demonstrates our proposed function. For, *f(20C, 2W, 3S, 0U, 10N, 10P, 2V)* this would mean that the network quality is comprised of 20 units of monetary cost, 2 units of power requirements, 3 units of security, no user preference, 10 units of network conditions, 10 units of network performance and 2 units of velocity.

There are a number of issues in the aforementioned VHDF quality function that ought to be noted. The diverse characteristics in the function have different units; for instance, 1 unit of *C* is not necessarily equal to 1 unit of *W* or 1 unit of *S* or any other handoff characteristic. Secondly, for some characteristics such as security, the conception of a “unit of security” is not clearly definite or perhaps not measurable in any direct way. A further point that needs to be noted is that the network quality Q clearly suggests that in order to have vertical handoff, various tradeoffs between the different factors must be considered. For example, as c increases, f decreases, because increased security most likely causes a fall in performance. As a result, increasing c and f concurrently might not be possible for some networks. Furthermore, as the monetary cost decreases, the network conditions might deteriorate due to the inferior service being provided. Therefore, the calculation of the network quality Q must be done in consideration of all the different factors that are most desired within the network and with recognition that *a, b, c, d, e, f, g* cannot all be maximized for a single network and therefore tradeoffs must be considered.

B. Analysis of Network Quality Q

A key issue in VHDF involves the identification of Q’s measurement unit. There are many different possibilities depending on how Q would be implemented. It could be an integer, real number or possibly an n-bit binary number. Q must represent some relative metric from which determinations as to whether Q is increasing or decreasing can be made. Q must also represent a metric from which predications as to how the network will behave are accurate for a specified environment and conditions. The change in Q should reflect the change in the network’s environment and should suitably map onto the desired handoff decision factors. If, for instance, a 2-bit binary number is used to symbolize the different levels of network handoff suitability (quality), then *11* could represent highly qualified network nominees, *10* good nominees, *01* less qualified nominees and *00* low quality nominees.

By having the network quality Q signified by comparative values such as n-bit numbers instead of a full spectrum of values the ability to observe how handoff decision changes over time is preserved. For example, as the user moves away from a certain network, e, which is a measure of the network conditions, N might degrade and as a result change the overall value of the Network Quality Q leading to new decisions taking place. Another scenario might also occur if a user is connected to a WLAN hotspot and after a period of time, the number of network users increases horrifically leading to severe deprivation in f, which is a measure of network performance P. In that case, the network quality Q would decrease significantly, although the user has been static, and a vertical handoff might be necessary depending on the quality of the other available network interfaces.

C. VHDF Prioritization and Evaluation

In order to allow for different circumstances, there is an apparent necessity to weigh each factor relative to the magnitude it endows upon the vertical handoff decision. Therefore, a different weight, w_i, for i = 1, 2, …, 7 is introduced as follows:

$$Q = f(w_1aC, w_2bW, w_3cS, w_4dU, w_5eN, w_6fP, w_7gV), \quad (3)$$

where *w1..w7* are weights for each of the characteristics. Each weight is proportional to the significance of a factor in the vertical handoff decision. Each network will have dissimilar unique weights which will differ from those of other heterogeneous networks. The values of the weight factors range from

$$0 \leq w_n \leq 1, \quad (4)$$

and the total of all the weights must be equal to 1:

$$w_1 + w_2 + w_3 + w_4 + w_5 + w_6 + w_7 = 1. \quad (5)$$

In a critical handoff decision where security is the main and only concern for instance, w_3 would equal 1 and all other weights would equal 0. VHDF will absolutely help in deciding the "best" moment and crossing point for vertical handoff. For example, *f (0.4aC, 0.1bW, 0.05cS, 0dU, 0.2eN, 0.1fP, 0.05gV)* would mean that the overall value of the network, relevant to vertical handoff, is heavily dependent on the monetary cost of the network. Security and velocity in this case have a small effect on the decision and user preference is not considered at all. This scenario also shows the priority ratios between the different characteristics; for instance monetary cost is twice as important as network conditions and quadruple times more imperative than power requirements and network performance.

Now we demonstrate a scenario that shows how the deployment of VHDF is uncomplicated and yet effective. Assume that a device detects a new network with a different interface. It calculates the network *quality Q* for its current network and for the newly detected network. The weights *w1..w7* would already have fixed (but different for each network) values that assign priorities to the various characteristics and *a, b, c, etc*. would store the measured metrics for each network characteristic. The function simply multiplies each weight factor by its relevant measured unit and their total is assigned to *Q*. The network with the highest *Q* is the preferred network. If the newly detected network receives a higher *Q* then vertical handoff takes place, otherwise the device remains connected to the current network.

Even though we could add the different factors in the vertical handoff decision function to obtain network quality Q i.e.

$$Q = w_1aC + w_2bW + w_3cS + w_4dU + w_5eN + w_6fP + w_7gV, \quad (6)$$

Moving around the terms in a mathematical way is not feasible since they all have different units. This implies that for example

$$w_1aC \neq Q - (w_2bW + w_3cS + w_4dU + w_5eN + w_6fP + w_7gV). \quad (7)$$

The reason is that the different factors have different units. For example monetary cost might be measured in dollars ($) while velocity in meters per second squared (ms^{-1}). And just like adding 5 apples to 4 bananas does not create 9 apples nor 9 bananas, but creates a set with 9 fruits, adding the abovementioned factors is not possible. Therefore, VHDF should only be used as a policy for deducing the quality of the different contesting networks present and determining the best candidate. By integrating the different network characteristics we generate a new entity that has a different unit than the original and therefore is incomparable to them. Q simply offers a reasonable, abstract measure of the handover suitability of any available network.

As discussed above, each factor has its own unique unit and consequently needs to be measured individually. Some factors could be measured directly, while others are non-quantitative and require further analysis. It is very reasonable to infer that monetary cost is measured in dollars (or any other currency), velocity in meters per second and power requirements in watts or joules; conversely, network conditions, performance, security and user preferences are more qualitative or consist of several different measures and need to be investigated in more detail.

In the case of security, there is no unambiguous and well defined way of determining a network's security. However, some of the aspects that could aid in determining a network's security include encryption, number of network users (the more users the greater the risk of intrusion or malicious attacks), authentication and whether a network operates in the unlicensed 2.4 GHz–2.5 GHz Industrial, Scientific, and Medical (ISM) frequency band or in a more confidential, licensed band. In the case of network conditions, a combination of available bandwidth, network latency and congestion (rate of packet loss) is considered necessary. Measuring and integrating these three properties is sufficient in presenting a full description of network conditions. Practical units of measurement for network performance could include Signal to Noise Ratio (SNR) which is the quantification of signal strength compared to background noise, and Bit Error Rate (BER), the percentage of bits that have errors relative to the total number of bits received in a network transmission.

Finally, a user preference is the most indefinite yet vital factor. By proactive handoff, the users or applications are involved in the vertical handoff decision and have the final decision on whether or not to handoff, regardless of the network conditions. By permitting the user to choose a preferred network the system is able to accommodate the user's special requirements. For example, the user might have preference for WLANs over WWANs or might prefer different networks in different locations or at different times.

In summary, although some of the factors proposed in the vertical handoff decision function cannot be directly measured, schemes can be formulated from the key indicators or various metrics could be combined to predict the overall quality of that factor. So therefore c, d, e and f can still be assigned numerical values, where the greater the value, the higher the quality of a network in terms of that factor.

IV. CONCLUSIONS AND FUTURE WORK

In this paper we have presented a *vertical handoff decision function*, *VHDF* which provides hand over decisions when roaming across heterogeneous wireless networks. It allows users to strategically prioritize the different network characteristics and assign weights to different network factors such as monetary cost, quality of service, power requirements, etc. VHDF is simple and can be easily applied to any vertical handoff approach. It significantly advances the system flexibility and extensibility and provides more accurate handoff decisions at any given time.

An issue that will be considered in future research work is the application of VHDF to multimedia applications. We shall address the fact that a better network quality, Q, does not necessarily mean better multimedia service. For example, A WLAN network might have a high Q, however because Voice over WLAN (VoWLAN) still provides poor voice quality, vertical handoff from a cellular WWAN might be an appalling choice.

There also still needs to be a tradeoff model that defines the minimal amounts of each factor to satisfy the quality needs of the system before vertical handoff could take place. And regrettably, for virtually the entire network characteristics discussed there is not enough validated data available to be able to tie the costs of using a particular technology to the level of a particular factor. This is an open research question that needs much more empirical work.

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