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An adaptive Policy-Based Vertical Handoff algorithm for Heterogeneous Wireless Networks

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Abstract

The next generation of wireless networks is envisioned as convergence of heterogeneous radio access networks. Since technologies are becoming more collaborative, a possible integration between IEEE 802.16 based network and previous generation of telecommunication systems (2G,..., 3G) must be considered. A novel quality function based vertical handoff (VHO) algorithm, based on proposed velocity and average received power estimation algorithms is discussed in this paper. The Short-Time Fourier analysis of received signal strength (RSS) is employed to obtain mobile speed and average received power estimates. Performance of quality function based VHO algorithm is evaluated by means of measure of quality of service (QoS). Simulation results show that proposed quality function, brings significant gains in QoS and more efficient use of resources can be achieved.

1. Introduction

Wireless technology provides different kinds of choices for its users, which vary in terms of coverage, bandwidth, latency, security and cost for both implementation and services. The next generation of wireless networks will enable different access networks to interoperate with each other to ensure global mobility and service availability. It is widely accepted that next generation mobile systems will be based on OFDMA; Meanwhile, OFDMA has already been adopted as the basis of mobile WiMAX. OFDMA inherently provides excellent support for advanced antenna technologies, such as MIMO, STC, and Beam forming that are essential to meet Next Generation performance goals [1]. The IEEE 802.16 family standards [2, 3] provide fixed and mobile broadband wireless access (BWA) and promise to deliver high data rate services over large areas. Based on efficiency and flexibility of the medium access control (MAC) and physical (PHY) layers, the IEEE 802.16 family is expected to support better QoS. The first line-of-sight (LOS) based IEEE 802.16 standard (802.16a), approved in 2001 which is in the 10-66 GHz range. In order to operate in non-line-of-sight (NLOS) scenarios, IEEE 802.16a, is revised in 2003, to support 2–11 GHz band. The result is published as IEEE 802.16d, in 2004, named IEEE 802.16-2004. The new IEEE 802.16e standard extends the 802.16d standard and provides mobility support in cellular deployments [3]. Due to rapid growth of request for wireless services, and also progress in BWA technology, future networks will have multi-layer structure for more capacity, better subscriber density management and ability to provide variety of services. The objective is to provide freedom of mobility and seamless connection anytime, anywhere to the best network, while each network has a heterogeneous structure. Determination of the “best” network is an open field of research.

Handoff is an act of maintaining an active connection while mobile user is moving through the network. In homogeneous cellular mobile networks, the handoff between cells is entitled “Horizontal Handoff”, whereas in heterogeneous networks, it is called “Vertical Handoff” (VHO) [4]. Traditional handoff algorithms are based on link quality or estimate of average received power. However, this measure is not sufficient for VHO, because other factors like mobile user velocity, network condition, user preferences, etc are not considered. Also because of complex structure of next generation networks, more precise and sophisticated method for link measurements is required.

Related works on cost function or Policy based VHO algorithms are as follows. Wang et al. [5] developed a two-dimensional, policy-based, VHO algorithm, which evaluates various metrics simultaneously, but the handoff targets of all the applications are restricted to a single network. If network fails to accommodate all the active applications, the user will lose all of its ongoing applications. Zhu et al. [6] extended Wang’s policy [5], and in that decision algorithm, cost function is calculated for any active application of each user, in a descending order of application priority. In this method decision process of one application is independent of
processes of other applications. In comparison with Wang’s policy, Zhu’s policy will obtain a higher system throughput, due to the flexibility in bandwidth usage. In [8], importance of velocity as an effective measure in the act of VHO decision-making is discussed but no exact mechanism for incorporation of velocity in cost function is offered. The proposed cost function in [7] is based on [4], which is not efficient. In above-mentioned literature, effect of velocity on efficiency of policy is not discussed. In addition, no exact method for estimation of measures like, average received power and velocity is mentioned. Because of heterogeneity, MAC and PHY of different networks are completely different so a unified approach must be taken into consideration for collection of specific measures from different networks. By using more sophisticated policy the throughput of multi layer network can be extended, also more efficient resource management for next generation of wireless networks can be achieved. In this paper, following contributions are proposed: (1) the proposed quality function includes essential VHO parameters. (2) By means of elimination procedure (which is also used in [6]) sensitivity of proposed method to type of requested service is eliminated and also active set of available services is prepared in real time. (3) Based on our previous work [8], a new framework for velocity and average received power estimation is proposed. (4) By means of incorporation of information of user’s velocity, more efficient resource management is achieved. This paper is organized as follows, Section (2) describes concept of quality function based VHO. Section (3) introduces proposed quality function, based on, novel method of velocity and average received power estimation. In section (4) simulation results of proposed VHO algorithm is shown. Section (5) concludes the paper.

2. Quality-Function Based VHO

The VHO decision-making is based on a policy based network structure. Due to convergence of applied networks, a unified approach is needed for process of measurement, storage, decision-making, and policy enforcement. In [7] the concept of policy based network structure is described. In the case of VHO, the policy database stores information regarding the metrics to be considered for VHO, where handoff metrics are the qualities that are measured to give an indication of whether or not a handoff is needed. In multi network environments, this is very challenging and hard to achieve, as there does not exist a single factor that can provide a clear idea of when to handoff. Signal strength, which is the chief metric in traditional horizontal handoffs, cannot be utilized for VHO decisions due to the overlaid nature of heterogeneous networks and the different physical techniques used by each network. Thus a natural question arises as, what factors should be considered in the act of handoff decision making. In order to meet the requirements the following decision factors are considered:

1- Type of Service: different types of services require different bandwidth (bit rate), latency and reliability.
2- Cost of Service: Variety of billing plans and options will probably influence the customer’s choice of network and as a result, handoff decision.
3- Quality of service: QoS is divided into three categories:
   3-1 Network conditions: Network quality parameters like, traffic, available bandwidth, latency and packet loss.
   3-2 Mobile entity conditions: speed, location information, mobility model. In VHO, the velocity factor has a larger weight and imperative effect in handoff decision making than in traditional hand-off. Because of heterogeneous structure of overlaid networks, handing off to an embedded network when traveling at high speed is discouraged, since a handoff back to the original network would occur very shortly afterwards.
   3-3 Channel Quality: Received signal (RS), average received power, Inter-channel Interference (ICI), Signal-to-Noise ratio (SNR), Bit Error Rate (BER).
4- Security: Because different networks can support different levels of security, Therefore security is one of the important factors in the VHO decision-making algorithms.
5- Power Requirements: Wireless devices have limited battery power. When the level decreases, handing off (or remaining connected) to a low power consumption network can increase usage time.

6- Proactive Handoff: by proactive handoff, the users are involved in the VHO decision making and they have the final decision on whether or not to handoff, regardless of the network conditions. Therefore, VHO is related to, too many parameters, which increases complexity of VHO process. In order to speed up and to reduce complexity of act of decision making, quality function based VHO algorithm is proposed. Quality function is described in the next section.

3. VHO Quality-Function

The VHO quality function is a composition of different parameters that are evaluated for each of $n^*b$ layer of the network. Each layer that has highest quality for providing the requested service, would be chosen. The quality function is as follows:

$$L_n = \arg \left( \max_{n} (Q^n) \right)$$  \hspace{1cm} (1)
Where $L_{\text{opt}}$ is optimum layer and $Q^n$ is the quality function calculated for layer $n$. $Q^n_s$ is called quality of each service, form $N_{\text{service}}$ available services in layer $n$. This is calculated by:

$$Q^n_s = \sum_{s=1}^{N_{\text{service}}} Q^n_s$$  \hfill (2)

The per-service goal $Q'^n_s$ for $s^{th}$ service in layer $n$:

$$Q'^n_s = \mathcal{E}_n Q^n_s$$  \hfill (3)

Where $\mathcal{E}_n$ is network elimination factor for $s^{th}$ service at layer $n$ and $\Omega^n_s$ is a measure of quality of $s^{th}$ service in layer $n$. The elimination factor, guaranties that if the required level of QoS is not available for $s^{th}$ service in layer $n$, this layer is immediately removed form active set of available layers. This factor is defined by:

$$\mathcal{E}_n = \prod_{k=1}^{N_{\text{meas}}} H^n_{s,j}$$  \hfill (4)

$H^n_{s,j}$ is defined by using step function, in order to eliminates a layer with less resource or lower level of QoS from active set of available network layers:

$$H^n_{s,j} = u(I - I_{\text{threshold}})$$  \hfill (5)

If constraint $I$ does not meet the required threshold $I_{\text{threshold}}$, the $s^{th}$ service cannot be supported. In order to specify the impact of each measure on user or network, the QoS factor is defined as a normalized value multiplied by weight of that QoS factor on QoS of the whole system. For example, if a real time service is requested while user is traveling a in a highway, velocity is a constraint on providing service and it has more importance than user preference. It is obvious that this factor results in less preferred service. The QoS factor is:

$$\Omega^n_s = \sum_{j=1}^{N_{\text{meas}}} \alpha^n_{s,j} \Omega^n_{s,j}$$  \hfill (6)

Where $\Omega^n_{s,j}$ is the normalized factor for layer $n$, $s^{th}$ service and $j^{th}$ measure, and $\alpha^n_{s,j}$ is the weight, which indicates the impact of QoS factor. Normalization is needed to ensure that values with different units are comparable. Natural log is considered as normalization function.

### 3.1. Proposed Policy based VHO

Because each user may request multiple services, each service must be prioritized individually for each session. In other words, each user's active sessions may be independently handed off to a different target layer.

First, mobile entity (ME) recognizes active layers of the network. Second, ME prioritizes its current active sessions and in the same time QoS measurements are done within ME and network access points. Third, the quality function is calculated for a service with the highest priority, by incorporation of QoS measures that are prepared by means of proposed velocity and average received power estimation algorithms. If user is classified “slow” it can receive, service from overlay and underlay networks based on other factors like RSS and bandwidth and if “fast”, the network with more coverage is preferred in order to reduce the unnecessary handoffs (decrease in throughput). The layer with more quality is the target for VHO. This procedure is repeated for every active session in the list. With this mechanism, if the constraints for one session cannot be met, only specific session is not supported. The procedure is shown in Figure 1.

### 3.2. Joint Velocity and Average received power Estimation

Based on our previous work [8], a joint estimator for next generation of wireless network is proposed. Because in handoff algorithms, instantaneous velocity is not required, the proposed method in [8] is modified in such a way that state of velocity is prepared in real time for act of VHO decision making. The DFT of finite-length segments of the RSS is obtained by banks of rectangular filters such that, each filter has different
Maximum of takes place in maximum Doppler frequency, which is proportional to mobile velocity. $(\hat{\nu} \propto f_d \cdot \lambda)$ in which $\lambda$ is wave length [8].

\[ \hat{\nu}_b = \arg \max \{ PSD_i(\nu) \} \] (8)

As it is seen in figure 3 increase in velocity can be interpreted as a Doppler spread in frequency domain. Thus, the mobile velocity can be obtained from estimated Doppler spread. First the estimated \( PSD \) is normalized to the detected maximum of \( PSD \) then due to symmetry, \( PSD \) is folded. Bandwidth of \( PSD \) is detected which is proportional to Doppler spread. In order to find the relative velocity of user we classify user’s mobility model into two classes, pedestrian and fast. Maximum frequency, extraction from estimated \( PSD \) of \( RS \) in frequency domain is done only in these two segments. The class that holds the estimated maximum shows state of velocity. In this algorithm maximum is searched only in pedestrian segment of estimated \( PSD \) of \( RS \), which limits search space and as a results increases estimation speed.

Shadow fading and path loss have slow variations therefore; they are present only in DC component of the estimated \( PSD \) of the \( RS \). For variable mobile speed, the duration of observation window \( L_r \) must be constantly adapted and the rate of adaptation is critical for performance of speed and power estimators. DC component of estimated \( PSD \) is adaptively extracted from different filters [8]:

\[ \hat{S}_{\nu} = \frac{1}{L_r \Delta F} \left| \int_{-\nu_r}^{\nu_r} \nu e^{j \nu t} \bar{y}[n] \, dt \right| \] (9)

Where $\nu_r$ is the estimated average received power, $L_r$ is window length $L_r$ is sampling interval and $F$ is normalization factor [8]. Active smoothing window is switched to another window in which its duration is selected proportional to inverse of estimated velocity for any iteration according to method proposed in [8]. Better averaged received power estimation, reduces number of unnecessary handoffs, which reduces unnecessary signaling and waste of bandwidth. The schematic of joint average received power and velocity estimator is shown in figure 4.

4. Simulation Results

Figure 5 shows simulation environment. In this coverage area, four networks with different data rates are present. Network 1 and 3 represent 802.11n with 1 and 1.5 Mbps upload bit rate respectively. Network 2 is presumed to be GPRS network, which supports approximately 100 users simultaneously. Each user can occupy up to 8 slots, where each slot can support 21.4kbps [7]. Network 4 represents MIMO, 10MHz bandwidth, IEEE 802.16e with 2Mbps available upload
bit rate [1]. A user, who is in overlapped coverage area of all of four networks, must decide the preferred network, and also whether to execute a VHO or not. Two different services, constant bit rate (CBR) 50Kbps and available bit rate (ABR), which is a uniformly distributed between 0 and 0.95 Mbps (live video streaming), with three constraints are considered. Constraints are RSS, Velocity, and available bandwidth. Typical maximum Doppler frequencies are considered within the range of 0-100 Hz. Users are assumed to be uniformly distributed within the overlay cells. Region of interest is overlapped coverage area. Let request arrival rate be Poisson distributed with a mean of $\lambda$ and request-holding time be exponentially distributed with the mean of $1/\mu = 5$ min. The traffic load in this area is:

$$\rho = \lambda / \mu$$

(10)

Resource allocation is based on type of requests, where handoff calls are given a higher priority than new calls. The VHO quality function for requested services CBR and ABR respectively are:

$$Q^*_r = E_r(\text{R}_r)E_r(\text{B}_r)(\text{V}_r)(\ln \text{B}_r + 1/\ln \text{V}_r)$$

$$Q^*_r = E_r(\text{R}_r)E_r(\text{B}_r)(\text{V}_r)(\ln \text{B}_r + 1/\ln \text{V}_r)$$

(11)

Where $B_{req}$ is user-requested bandwidth, $B_n$ is available bandwidth in $n$th layer, $R_n$ is RSS from $n$th network and $R_{th}$ is received power threshold which is considered 60dBm in simulation. $V_n$ denotes estimated velocity while user is connecting to $n$th layer and $V_{th}$ is velocity threshold which is considered 5km/h in simulation. Elimination factor for velocity is defined as follows:

$$E_{1,2}(V_{th}) = u(\sqrt{V} - V_{th})$$

(12-a)

$$E_{1,2}(V_{th}) = 1 - u(\sqrt{V} - V_{th})$$

(12-b)

Because higher bandwidth and lower velocity brings more quality, normalized form of these parameters (by means of natural logarithm function) are considered. RSS is not considered due to multi-path, Raleigh and shadow fading. Performance of proposed velocity and average received power estimators are shown in Figures 6 and 7 respectively. Throughput, blocking probability and allocated bandwidth are taken as performance criteria. Performance of proposed method is compared to RSS and cost function based algorithms, proposed in [6]. The user selects, optimum network by means of mentioned constraints and when a session cannot be supported, only a single session is blocked (user is not blocked.). Figure 8, shows Blockage versus traffic load for our proposed method in comparison with method in [6]. As it is seen, for different percentage of slow moving users the proposed algorithm effectively manages traffic of requests. When all of the users are “fast”, the proposed method brings

![Figure 6: Velocity Estimation performance for variable speed profile. SNR= 20 dB](image)

![Figure 7: Average received power estimation results for long term SNR= 20 dB](image)

![Figure 8: Blocking Probability in 802.11n based networks vs request Load](image)

![Figure 9: Throughput vs Request Load](image)
equal blocking probability. Figure 9 shows that throughput is improved without increase in blocking probability, which refers to better resource allocation. Throughput refers to ratio of the actual data rate over the requested rate. In RSS based method network 2 is mostly selected, since it provides strongest signal. Which means, lower effective bandwidth and also unbalanced traffic assignment. Because there is no traffic management mechanism in [6], bandwidth allocation starts from underlay 802.11 networks and when there is no available bandwidth, VHO to upper layer is triggered. Fast mobile users pass through coverage area in short period of time and many unnecessary handoffs are triggered. In this situation, although there is enough bandwidth in upper layers, the effective available bandwidth is not properly allocated and the session or the user is going to get blocked. Figure 10 shows allocated bandwidth in comparison with available band width. As it is seen better resource sharing between different networks results in better overall performance for the whole system. Network utilization is balanced by means of velocity information.

5. Conclusion

Next generation of wireless networks offer verity of services by means of cooperation between diverse networks. This structure requires more efficient, adaptive and intelligent vertical handoff protocol. In this paper, new policy-based VHO decision-making algorithm has been developed to maximize the benefit of handoff for both user and network. By means of considering, effect of velocity and also incorporation of unique velocity and average received power estimation algorithm better traffic management is possible and as a result average Blockage probability is decreased. In addition, throughput for mobile terminals with multiple active sessions is increased. Numerical results demonstrate improvement in quality of service and a more efficient use of resources.

6. References


