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Predictive RSS with Fuzzy Logic based Vertical Handoff Decision Scheme for Seamless Ubiquitous Access

Sunisa Kunarak and Raungrong Suleesathira
King Mongkut's University of Technology Thonburi
Thailand

1. Introduction

Currently, adverse wireless and mobile networks including Worldwide Interoperability for Microwave Access (WiMAX), Wireless Local Area Network (WLAN), Third Generation (3G) mobile communications such as Universal Mobile Telecommunications Systems (UMTS), Wideband Code Division Multiple Access (WCDMA) and Bluetooth as shown in Fig. 1, have emerged and continuously developed to achieve high-speed transmission. The network characteristics are summarized in Table 1. However, no one network can provide all types of desired services, e.g. wide coverage, high bandwidth and low access costs. For example, WLAN provides high data rates within limited coverage areas, e.g. hotel, airport, campus and other hotspots whereas UMTS provides lower data rates over a larger coverage area.

Therefore, one of the challenges in the next generation of wireless communications (McNair & Fang, 2004) ; (Frattasi et al., 2006) ; (Boudriga et al., 2008) is the integration of existing and future wireless technologies and supporting transparent and seamless vertical handoffs without degrading quality of services (QoS) between these heterogeneous networks (Kassar et al., 2008) ; (Haibo et al., 2009). This will need a multi-interfaced terminal which can change connections during inter-network movement. Received Signal Strength (RSS) based handoff scheme is commonly used to initiate a handover (Pollini, 1996) ; (Pahlavan et al., 2000) ; (Majlesi & Khalaj, 2002). In heterogeneous wireless networks, RSS is not however sufficient for a vertical handoff decision because the RSS of different networks cannot be compared directly, and moreover, RSS cannot reflect network conditions adequately. In order to develop vertical handoff decisions, new metrics such as service types, monetary cost, network conditions, mobile terminal conditions and user preference should be used in conjunction with RSS measurement. In policy-based approaches, multi-criteria are needed not only for decision when the handover occurs but also determine which network should be chosen for user choice and intervention (Nkansah-Gyekye & Agbinya, 2008) ; (Stevens-Navarro et al., 2008) ; (Sun et al., 2008) ; (Nay & Zhou, 2009) ; (Haibo et al., 2009).

In (Song & Jamalipour, 2008), a merit function is proposed to evaluate network performance based on user preferences and adopted to find the best possible network for users. However, the counter to ensure the conditions in handoff policy consistently true is fixed which is not adjusted to the mobile computing and network environment. The approach proposed in (Chang & Chen, 2008) determines the optimal target network in two phases, i.e., RSS prediction and Markov decision process (MDP). Predicting RSS can minimize the dropping

probability but time complexity of this MDP-based predictive RSS approach depends on the number of WLANs and WMANs (Wireless Metropolitan Area Networks). Moreover, there is no dwell timer to check the condition of RSS comparison in order to avoid ping-pong effect. Besides RSS, mobile station velocity and movement pattern are important factors for handoff decision procedure (Lee et al., 2009). The movement-aware vertical handoff algorithm avoids unnecessary handovers by adjusting the dwell time adaptively and predicting the residual time in the target cell. Its algorithm has to estimate velocity and direction of the mobile in the first step which is the location update procedure. If the mobile movement is irregular suddenly, the estimation would not be precise and result in an error decision. Due to a robust mathematical framework for dealing with impression and uncertainty problem, fuzzy logic based network selection algorithms have been proposed (Majlesi & Khalaj, 2002) ; (Tansu & Salamah, 2006) ; (Stoyanova & Mähönen, 2007) ; (Xia et al., 2008) ; (Haibo et al., 2009). Fuzzy logic theory based quantitative decision algorithm (FQDA) (Sivanandam et al., 2007) has an advantage over traditional fuzzy logic algorithm which there is no need to establish a database to store rule bases. The vertical handoff algorithm presented in (Xia et al., 2008) also used FQDA for the optimized network selection but it considers only network conditions. Vertical handoff scheme should balances against user satisfaction and network efficiency for different types of service applications.
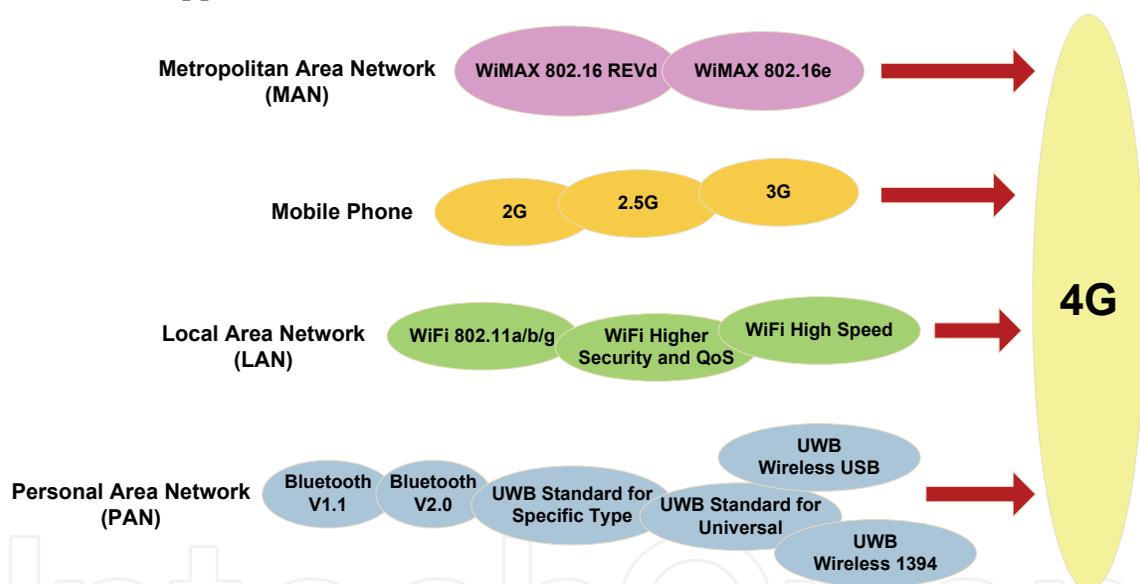

Fig. 1. Evolution of wireless and mobile networks toward 4G ubiquitous access

In this paper, we presented a vertical handoff scheme satisfying between user requirement and network conditions and avoiding unnecessary handoffs as well. The upper and lower bounds of dwell time depend on the service types i.e. real time and nonreal time services. The policy is to minimize handoff delay for real time service and prolong staying time for nonreal time services if the mobile node stays in WLAN/WiMAX while handoff from UMTS to the WLAN/WiMAX is the last time the signal strength reaches the acceptable level. Back propagation neural network is used to predict RSS. RSS of current serving network and predictive RSS of target networks are used to consider whether the handoff should be triggered. In the network selection procedure, the merit function is adopted to find candidate networks satisfying preference of a user. FQDA using five handoff metrics, RSS, bandwidth, number of users, power consumption and monetary cost as the input can determine the optimal target network.

The remainder of paper is organized as follows. Section 2 explains the RSS prediction using back propagation neural network. Merit function and dwell time are described in section 3 and 4, respectively. In section 5, network selection using FQDA is presented. Vertical handoff scheme is proposed in section 6. Section 7 presents and discusses the simulation results. The conclusion is finally given in section 8.

Network Characteristic	IEEE 802.11g WiFi	IEEE 802.16e Mobile WiMAX	3G UMTS/WCDMA
Coverage	100-300 (m)	1.6-5 (km)	3-10 (km)
Bandwidth	54 Mbps	30 Mbps (10 MHz BW)	1.8-14.4 Mbps (HSDPA+HSUPA)
Frequency	2.4 GHz	2-6 GHz (licence)	1920-1980 MHz (uplink) 2110-2170 MHz (downlink)
Channel Bandwidth	5 MHz	5, 7, 10 MHz	5 MHz
Number of Channels	13	Depending on Country	12
Number of user/channel	1	Many (100, ...)	Many (order of magnitude: 25; data rate decreases)

– *HSDPA:* High Speed Downlink Packet Access

– *HSUPA:* High Speed Uplink Packet Access

Table 1. Network Characteristics

2. Received signal strength prediction using back-propagation neural network

Although the RSS with hysteresis and threshold approach can reduce the number of unnecessary handoffs, this approach results in a low data rate and high dropping probability since the mobile node receives too weak RSS from the serving network at the handoff point. Given the future values of the RSS of each neighbor base stations, the handoff process would perform before the RSS becomes weak. Consequently, prediction technique based scheme with hysteresis is beneficial in avoiding unnecessary handoff, minimizing the handoff dropping probability as well as obtaining higher data rate. We use the back-propagation training algorithm for a two-layer network as in Fig. 2 to predict the future RSS. The input and output of the hidden layer are denoted as z_i and y_j, respectively while the output of the network is denoted as o_k for $i = 1, 2, ..., I, j = 1, 2, ..., J$ and $k = 1, 2, ..., K$. These input and output values can be arranged in a vector notation as $\mathbf{z} = [z_1, z_2, ..., z_I]^t$, $\mathbf{y} = [y_1, y_2, ..., y_J]^t$ and $\mathbf{o} = [o_1, o_2, ..., o_K]^t$. The weight v_{ji} connects the ith input with the input to the jth hidden node and the weight w_{kj} connects the output of the jth neuron with the input to the kth neuron. Given P training pairs of inputs and outputs $\{(\mathbf{z}_1, \mathbf{d}_1), (\mathbf{z}_2, \mathbf{d}_2), ..., (\mathbf{z}_P, \mathbf{d}_P)\}$ the weights are updated after each sample pair as follow (Zurada, 1992) ; (Haykin, 2009):

1. For $p = 1$, submit training pattern $\mathbf{z}_P$ and compute layer responses

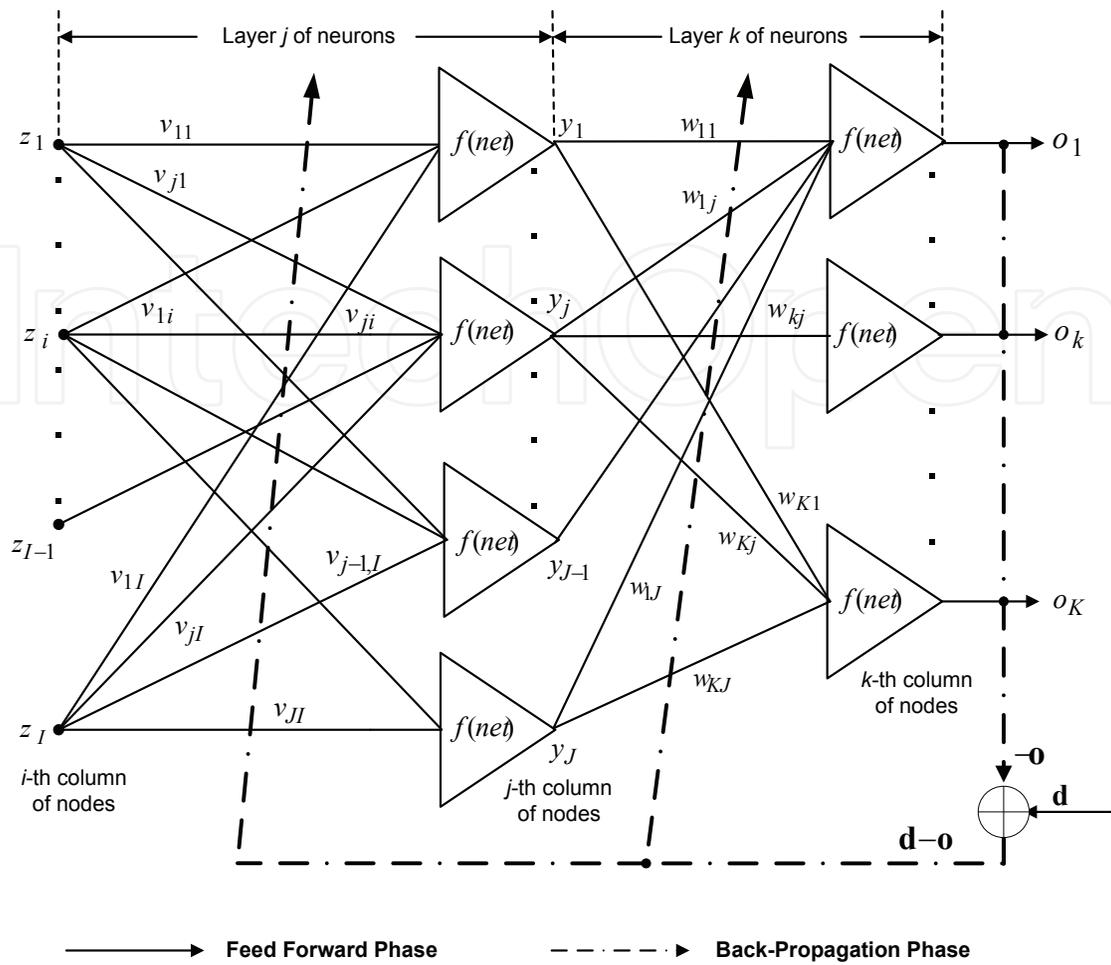$$y_j = f\left(\sum_{i=1}^{I} v_{ji} z_i\right) \tag{1}$$

Fig. 2. Two-neuron layer network

$$o_k = f\left(\sum_{j=1}^{J} w_{kj} y_j\right) \tag{2}$$

when $\quad f(net) \underset{=}{\triangle} \frac{2}{1+\exp(-\lambda net)} - 1 \quad$ and $\quad \lambda > 0.$

2. Calculate errors

$$\delta_{ok} = \frac{1}{2}(d_k - o_k)\left(1 - o_k^2\right) \tag{3}$$

$$\delta_{yj} = \frac{1}{2}\left(1 - y_j^2\right)\sum_{k=1}^{K} \delta_{ok} w_{kj}. \tag{4}$$

3. Adjust the output layer weights and hidden layer weights using the delta learning rule

$$w_{kj} \leftarrow w_{kj} + \eta \delta_{ok} y_j$$
$$v_{ji} \leftarrow v_{ji} + \eta \delta_{yj} z_i \quad ; \qquad \eta > 0.$$

4. Increase $p = p + 1$ and if $p < P$ then perform step 1 until $p = P$.

The learning procedure stops when the cumulative final error in the entire training set,

$$E = \sum_{p=1}^{P} \frac{1}{2} \left\| \mathbf{d}_p - \mathbf{o}_p \right\|^2,$$

below the upper bound E_{max} is obtained otherwise initiate the new training cycle.

We implemented the back-propagation algorithm to predict the RSS in UMTS by using four input nodes, four hidden nodes and one output node. As shown in Fig. 3, the predictive RSS matches the actual RSS values very well.
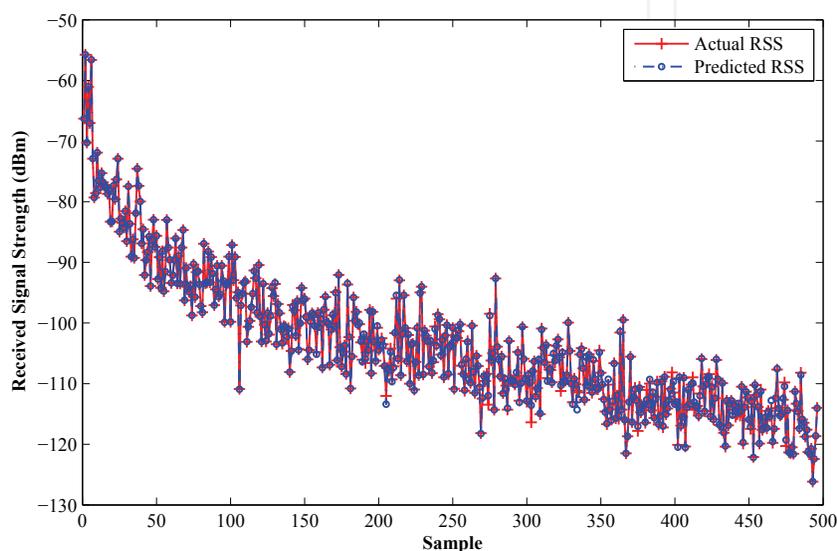

Fig. 3. Prediction results by using back-propagation neural network

3. Merit function

Merit function is a measurement of the benefit obtained by handing over to a particular network. It is calculated for each network available in the vicinity of the user. The neighbor networks with higher value than the serving network become candidate networks. The merit function for wireless network n is calculated as (Song & Jamalipour, 2008)

$$F_n = E_n \sum_i w_i \ln(p'_{n,i}) \tag{5}$$

where $p_{n,i}$ is the ith QoS factor in network n, $p'_{n,i} = p_{n,i}$ if the increase of $p_{n,i}$ contributes the merit value to network n, while $p'_{n,i} = \frac{1}{p_{n,i}}$ if the decrease of $p_{n,i}$ contributes the merit value, w_i is the weight assigned to the ith QoS factor with $\sum_i w_i = 1$, E_n is the elimination factor of network n. The value of E_n is either 0 or 1 decided by QoS requirements based on user preference and service applications. For example, $E_n = 0$ if the data rate supported by a network is lower than that required by the current service, otherwise $E_n = 1$. Suppose that the current service is real time video, the UMTS should be deleted from the candidates by the eliminate factor i.e. $E_n = 0$ due to very high bandwidth unprovided. The considered QoS

parameters consist of bandwidth (BW), delay (D) and monetary cost (C) given in the merit function as

$$F_n = E_n \left(w_{BW} \cdot \ln p_{n,BW} + w_D \cdot \ln \frac{1}{p_{n,D}} + w_C \cdot \ln \frac{1}{p_{n,C}} \right). \tag{6}$$

4. Dwell time

The traditional handover decision policy based on RSS, hysteresis and threshold can cause a serious ping-pong effect if the mobile node moves around the overlap area. To alleviate sequential handovers evoked too frequently, the conditions for handoff decision must continue to be true until the timer expires in order to determine when the handover occurs (Pahlavan et al., 2000) ; (Kassar et al., 2008). The duration of dwell timer can be adjusted according to the movement of mobile node and perceived QoS from each neighbor network. If the merit of target network is much better than the current serving network, the dwell timer is shortened, and if movement direction is irregular, i.e. ping-pong effect, the dwell timer is extended. This leads the dwell timer defined as

$$t_d = \min[ubound(t_d), \delta] \qquad \text{s.t.} \qquad \delta = \max \left(lbound(t_d), (1 + \tilde{p}\tilde{p}_t) \cdot \frac{F_{\text{cur}}}{F_{\text{targ}}} \cdot \hat{t}_d \right) \tag{7}$$

where $ubound(t_d)$ and $lbound(t_d)$ denotes the upper and lower bounds of dwell timer (t_d), $\hat{t}_d$ is the default value of the dwell time, pp_t is the ping-pong flag at time t which is set to 1 if direction change between time t and $t-1$ more than 90 degree, otherwise $pp_t = 0$. $\tilde{p}\tilde{p}_t$ is an average ping-pong flag until time t given by (Lee et al., 2009)

$$\tilde{p}\tilde{p}_t = \begin{cases} 1 & avg(pp_t) > 0 \\ 0 & \text{otherwise} \end{cases} \tag{8}$$

$$avg(pp_t) = \sum_{i=1}^{t} \alpha(1-\alpha)pp_{t-i+1} \tag{9}$$

where $0 < \alpha \leq 1$ is an exponential smoothing factor. Note that we use the random waypoint mobility model (Haykin, 2009) to determine the location and movement of mobile node which enables us to calculate the mobile directions.

5. Fuzzy logic using quantitative decision algorithm based network selection

In this paper, fuzzy logic using quantitative decision algorithm (FQDA) is used as an handoff decision criteria to choose which network to hand over among different available access networks. These criteria can be classified as a multi-criteria strategy regarding to network, terminal, user preference and services. The FQDA has three procedures: fuzzification, quantitative evaluation, and quantitative decision (Sivanandam et al., 2007) ; (Xia et al., 2008).

5.1 Fuzzification

The membership function shown in Fig. 4 has the fuzzy set: very low, low, medium, high and very high. The constants $M_{\text{min}}, M_2, M_3, M_4, M_{\text{max}}$ can be specified with different values according to the specific characteristics of the network being considered. Using five handoff metrics, received signal strength (RSS), bandwidth (BW), number of users (NU), power

consumption (P) and monetary cost (C), the presentation of a member function is

$$\mu_{\text{QoS}} = [\mu_{VL}, \mu_L, \mu_M, \mu_H, \mu_{VH}]_{\text{QoS}} \tag{10}$$

where QoS represents the fuzzy variables including RSS, BW, NU, P and C. For example, when the input value in a certain candidate network is $RSS = P$, that network has a membership degree of the fuzzy variable RSS is $[0, 0, 0, 0.18, 0.62]_{RSS}$.
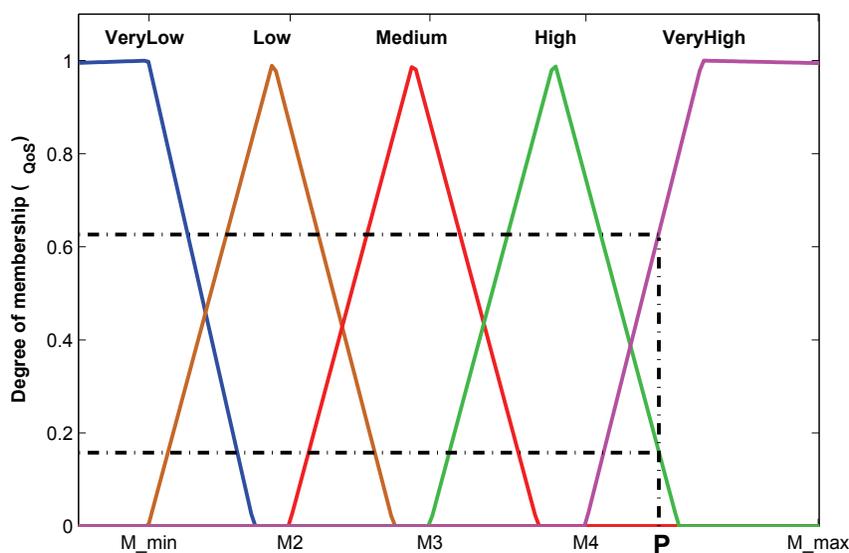

Fig. 4. Membership function

5.2 Quantitative evaluation

Quantitative evaluation is denoted as $Q_{\text{QoS}} = [Q_{VL}, Q_L, Q_M, Q_H, Q_{VH}]_{\text{QoS}}$ which can be specified with different values according to the specific characteristics of the network. We assign $Q_{\text{QoS}} = [0, 0.25, 0.5, 0.75, 1]_{\text{QoS}}$ when QoS is RSS and BW, and $Q_{\text{QoS}} = [1, 0.75, 0.5, 0.25, 0]_{\text{QoS}}$ when QoS is NU, P and C. The quantitative evaluation value (QEV) of each QoS metric for a candidate network n is a sum of evaluated membership degree calculated as

$$QEV_{n,\text{QoS}} = Q_{\text{QoS}} \mu_{\text{QoS}}^T. \tag{11}$$

5.3 Quantitative decision

In order to balance against user satisfaction and network efficiency, each $QEV_{n,\text{QoS}}$ should be weighted to reflect the important of the QoS factor. The quantitative decision value (QDV) of network n is therefore defined as

$$QDV_n = W_{RSS}QEV_{n,RSS} + W_{BW}QEV_{n,BW} + W_{NU}QEV_{n,NU+}W_PQEV_{n,P} + W_CQEV_{n,C}. \tag{12}$$

For each QoS metric, the weight can be calculated by

$$W_{\text{QoS}} = \frac{\phi_{\text{QoS}}}{\Phi} \tag{13}$$

where ϕ_{QoS} is a function of mean and variance of $QEV_{n,\text{QoS}}$. The mean, m_{QoS}, and variance, σ_{QoS}, of the $QEV_{n,QoS}$ are estimated as follows:

$$m_{\text{QoS}} = \frac{1}{N} \sum_{n=1}^{N} QEV_{n,\text{QoS}} \tag{14}$$

$$\sigma_{\text{QoS}} = \frac{1}{N-1} \sqrt{\sum_{n=1}^{N} \left(QEV_{n,\text{QoS}} - m_{\text{QoS}} \right)} \tag{15}$$

where N is the number of networks. The function ϕ_{QoS} depending on the mean and variance of $QEV_{n,QoS}$ is given as

$$\phi_{\text{QoS}} = \exp(-m_{\text{QoS}} + \sigma_{\text{QoS}}). \tag{16}$$

Once we have ϕ_{QoS} for all QoS merit, we can calculate Φ which is $\Phi = \phi_{RSS} + \phi_{BW} + \phi_{NU} + \phi_P + \phi_C$. To select the most optimal network from those available in the candidate list, the network with largest QDV becomes the handoff target network.

6. Vertical handoff scheme with predictive RSS and fuzzy logic

The proposed vertical handoff algorithm consists of two steps: network QoS monitoring to decide whether handoff procedure is triggered, network selecting to determine which access network should be chosen. Handoff trigger is related to the measured and predicted RSS whereas network selection is related user preference. The service application types, real time and nonreal time, are used in conjunction with duration of signal strength measurements. We proposed two vertical handoff algorithms which one is for the mobile node located in UMTS and another one is for that is located in WLAN/WiMAX as shown in Fig. 5.

In Fig. 5, when a mobile node is in UMTS, the Predictive RSS (PRSS) is first used to help the mobile know whether it is moving toward the target network during dwell time by comparing the PRSS with the maximum threshold ($\text{RSS}_{\text{max\_th\_WL/WM}}$). It is beneficial to handoff if the residence time (t_{res}) in the target network is more than the delay cause by the handoff procedure. Therefore, the condition $t_{res} > (t_{hd} + t_{mu})$ should be also satisfied where t_{hd} and t_{mu} are handoff delay time and make up time, respectively. The residence time in the target network can be predicted by using mobile node velocity and the range to the target network boundary. The lower and upper bounds to calculate the dwell time are chosen based on the handoff policy which is to attempt to prolong the time staying in WLAN/WiMAX for nonreal time services. In addition to take into account both PRSS and residence time, handoff to the target network has to be performed providing the RSS of current serving BS lower than the threshold ($\text{RSS}_{\text{th\_UMTS}}$) in order to prevent the call from being dropped. In network selection procedure, candidate networks are found by comparing merit values of the target networks satisfying the mentioned conditions. If the PRSS is not larger than the high threshold and the RSS of the current serving network is less than the threshold, the available network having $F_{\text{targ}} > 0$ is selected into the list. However, if the PRSS is larger, $F_{\text{targ}} > F_{\text{cur}}$ is the condition to assure that its performance is continuously better than the current one. The network in the list with the largest QDV is the selected networks.
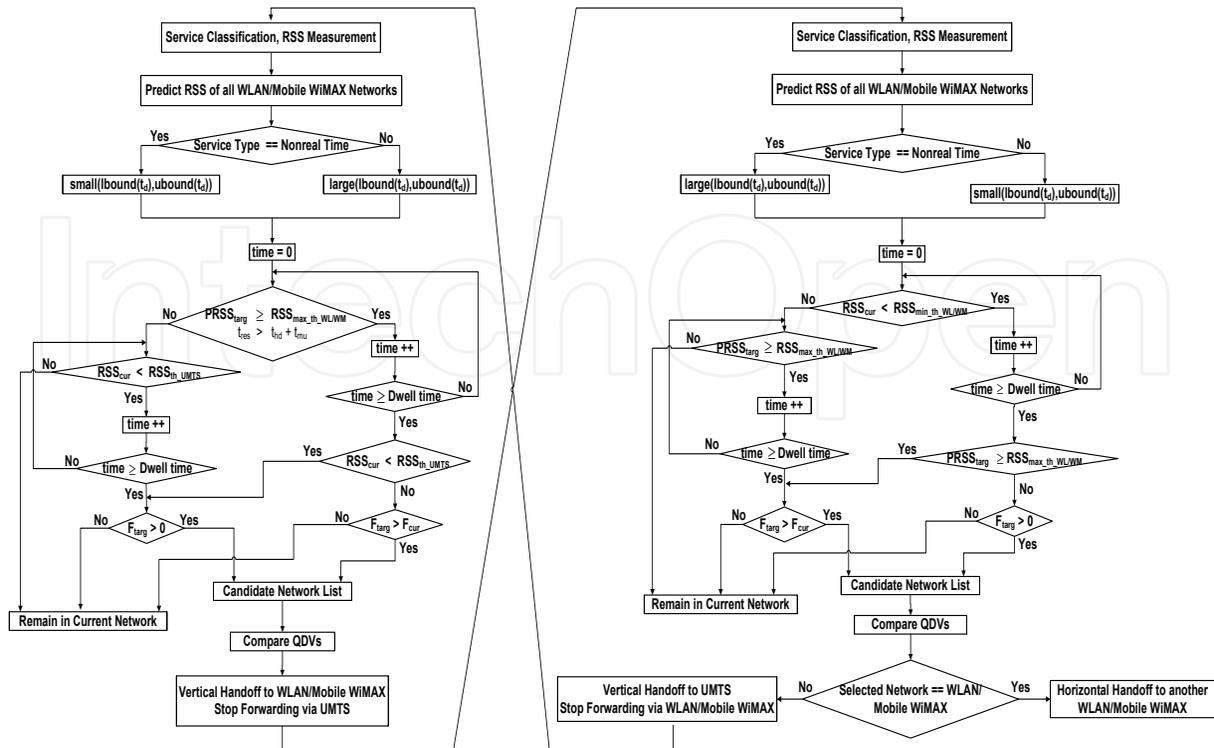
Fig. 5. Handoff decision algorithm when a mobile node is in UMTS or in WLAN/WiMAX

When a mobile node stays in WLAN/WiMAX, it starts working if the RSS of the current serving network is less than the minimum threshold ($RSS_{min\_th\_WL/WM}$). The lower and upper bounds for the dwell time calculation are short for real time applications to reduce the handoff delay otherwise it is longer for nonreal time applications. Then the mobile node checks whether the PRSS of each target network is stronger than the maximum threshold ($RSS_{max\_th\_WL/WM}$). The target networks are candidates if their merit values excel the current one or greater than zero. Finally, fuzzy logic is used to find the largest QDV network as the handoffed network. If there is no selected network, it handoffs to UMTS. The network selection order is $WLAN/WiMAX > 3G$ due to lower cost and better QoS.

7. Simulation results

This section evaluates the performance of the proposed handoff decision mechanism (i.e., denoted by PRSS+FQDA) by simulating heterogeneous wireless networks where UMTS, WLAN and WiMAX overlay as shown in Fig. 6. The channel propagation model used for the RSS received by a mobile node is different in different networks. Given the distance between a mobile node and a base station is $d(meters)$, the $RSS(d)$ in UMTS is

$$RSS(d) = P_t - PL(d) \tag{17}$$

where P_t is the transmit power, and $PL(d)$ is the path loss at distance d which is defined as (Bing et al., 2003)

$$PL(d)_{dB} = S + 10n\log(d) + \chi_\sigma \tag{18}$$

where S denotes the path loss constant, n denotes the path loss exponent and χ_σ represents the shadow effects which is a zero-mean Gaussian distributed random variable (in dB) with standard deviation σ (also in dB). We use $S = 5$ and $n = 3.5$.

In WiMAX, the path loss at distance d is formulated by (Betancur et al., 2006)

$$PL(d)_{\mathrm{dB}} = 20\log\left(\frac{4\pi d_0}{\lambda}\right) + 10n\log\left(\frac{d}{d_0}\right) + \chi_\sigma \tag{19}$$

where the first term represents the free space path loss at the reference distance d_0, λ is the wavelength. We set n to 4 and a carrier frequency to 3.5 GHz.

In WLAN, the RSS received by the mobile node is computed based on the propagation model as (Chang & Chen, 2008)

$$RSS(d)_{\mathrm{dBm}} = 10\log\left(\frac{100}{(39.37d)^\gamma}\right) \tag{20}$$

where γ denotes the environmental factor of transmissions which is set to 2.8. Several simulation parameters are summarized in Table 2.
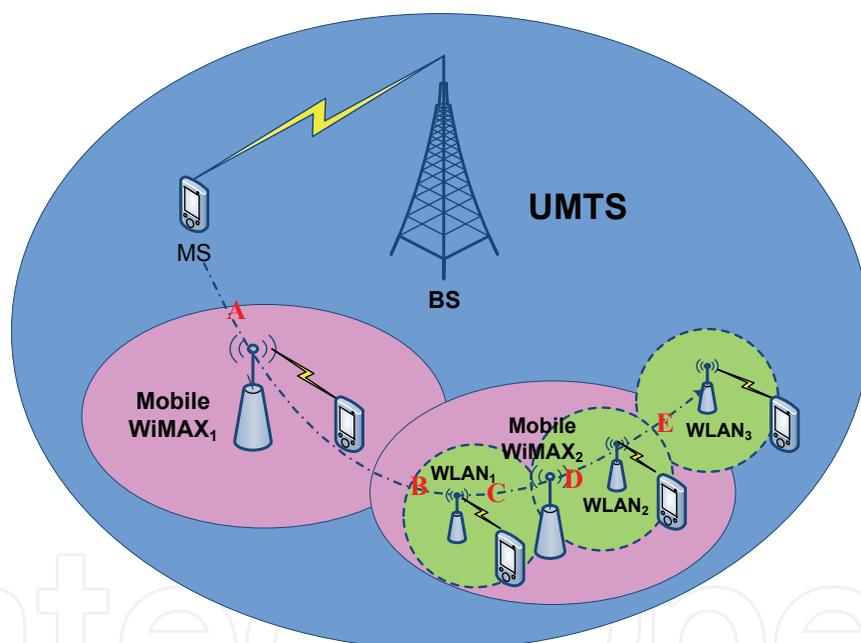
Fig. 6. Mobile model in heterogeneous networks integrating with WLAN, Mobile WiMAX and UMTS

7.1 Network selection performance

In the first simulation, the mobility of a mobile node is fixed according to the path from A to E as seen in Fig. 6. The user speed is 10 m/s and using a 64 kbps service. The calculated FQDA where the handoffs occurred at location A, B, C, D and E are shown in Table 3. The selected network at each handoff location has the largest QDV. The results indicate that the proposed PRSS+FQDA approach can trigger whether handoff is needed. If it is needed, it can choose the optimal network as a target network as well.

Simulation Parameters	Values
Cell radius of UMTS/WLAN/Mobile WiMAX	3000/100/1500 (m)
Transmission Power of UMTS/WLAN/Mobile WiMAX	1/0.1/0.5 (w)
$RSS_{min\_th\_WL}/RSS_{max\_th\_WL}$	-85/-72 (dBm)
$RSS_{min\_th\_WM}/RSS_{max\_th\_WM}$	-102/-85 (dBm)
RSS_{th_UMTS}	-119 dBm
small $(lbound(t_d), ubound(t_d))$/large $(lbound(t_d), ubound(t_d))$	(1,5)/(4,20)
Default value of dwell time $(\hat{t}_d)$	2 s
Handoff delay time (t_{hd})/ Handoff make up time (t_{mu})	1/1 (s)
Bandwidth of UMTS/WLAN/Mobile WiMAX	7.2/11/15 (Mbps)
$w_{BW}/w_D/w_C$ for 64/96/128 kbps service	(0.3/0.5/0.2)/(0.4/0.3/0.3)/ (0.5/0.3/0.2)
Arrival rate (Poisson distribution)	3 s
Average holding time (Exponential distribution)	1 s
Monetary cost of UMTS/WLAN/Mobile WiMAX	0.8/0.4/0.6
Power consumption of UMTS/WLAN/Mobile WiMAX	0.8/0.2/0.4
Number of UMTS/WLAN/Mobile WiMAX	12/13/15
User capacity/channel of UMTS/WLAN/Mobile WiMAX	50/1/100
Velocity (random waypoint mobility)	1-30 m/s

Table 2. Simulation Parameters

7.2 Handoff decision performance

In this subsection, we present some simulation results to show the performance of the proposed PRSS+FQDA approach by comparing number of handoffs, handoff call dropping probability (P_h) and Grade of Services (GoS). The GoS metric is given by (Tansu & Salamah, 2006);(Chang & Chen, 2008)

$$GoS = P_n + kP_h \tag{21}$$

where P_n is a new call blocking probability and k is the penalty. The impact of the handoff dropping is over the new call blocking since dropping connections results in the revenue loss more than blocking new connections. The recommended range of k is 5 to 20 which $k = 10$ in this simulation.

The proposed PRSS+FQDA approach is compared to 1) the predicted RSS based approach with two thresholds as an interval of hysteresis threshold (HT) (denoted by PRSS+HT) (Pollini, 1996);(McNair & Fang, 2004);(Kassar et al., 2008), 2) the neural network based approach using the Self-Organizing Maps (SOM) (Stoyanova & Mähönen, 2007). The benefit of handoff decision making process using a SOM algorithm is an adaptive inherent organizing technique but it does not guarantee finding the weight vector, corresponding to the network with the best parameter at a time. For training the winner-take-all learning in Fig. 7, the 30-dimentional input vector is generated as

$$\mathbf{x} = \{QEV_1^{RSS} \quad QEV_1^{BW} \quad QEV_1^{NU} \quad QEV_1^{P} \quad QEV_1^{MC},..., \quad QEV_6^{RSS},..., \quad QEV_6^{MC} \} \tag{22}$$

where six networks are in the scenario. The output node satisfying the following condition is the winner

Location	Networks	QDV	Target
A	$Mobile\ WiMAX_1$	0.793	$Mobile\ WiMAX_1$
	$UMTS$	0.219	
B	$MobileWiMAX_2$	0.569	$Mobile\ WiMAX_2$
	$WLAN_1$	0.517	
	$UMTS$	0.339	
C	$Mobile\ WiMAX_2$	0.561	$WLAN_1$
	$WLAN_1$	0.748	
	$UMTS$	0.275	
D	$Mobile\ WiMAX_2$	0.436	$WLAN_2$
	$WLAN_2$	0.459	
	$UMTS$	0.282	
E	$Mobile\ WiMAX_2$	0.391	$WLAN_3$
	$WLAN_3$	0.674	
	$UMTS$	0.317	

Table 3. QDVs of Candidate Networks

$$\|\mathbf{x} - \hat{\mathbf{w}}_n\| = \min_{i=1,\dots,6} \|\mathbf{x} - \hat{\mathbf{w}}_i\| \tag{23}$$

where the index n denotes the wining neuron number and $\mathbf{w}_n = [w_{n1} \quad w_{n2} \quad,\dots, \quad w_{n30}]$ is the weight vector to the nth neuron. Weight adjustment in the kth step of the winner uses the learning rule as (Zurada, 1992)

$$\mathbf{w}_n^{k+1} = \mathbf{w}_n^k + \alpha^k (\mathbf{x} - \mathbf{w}_n^k) \tag{24}$$

$$\mathbf{w}_i^{k+1} = \mathbf{w}_i^k \qquad \text{for} \qquad i \neq n \tag{25}$$

where α^k is a learning constant at the kth step.

In the simulation, an area in which there are three WLANs, two WiMAX and a UMTS is considered as shown in Fig. 6. We first evaluate the performance under number of users ranging from 100-2100, as seen in Figs. 8-10. Figure 8 illustrates that the proposed PRSS+FQDA approach yields the fewest number of vertical handoffs in comparison to the PRSS+HT and SOM approaches. Meanwhile, the numbers of vertical handoffs of all approaches increase when the number of users increases. The number of vertical handoffs using PRSS+FQDA is gently increases as the number of users increases, but that of PRSS+HT and SOM obviously increase. In Fig. 9, the dropping probability of PRSS+FQDA is fewest since it determines the optimal network regarding to the network condition whether it satisfies the preference of users and has a strong RSS as well. Accordingly, this yield the fewest GoS using the PRSS+FQDA approach as shown in Fig. 10.

The performance metrics under different arrival rates ranging from 6 to 16 are demonstrated in Figs. 11-13. The simulation results shown in Figs. 11-13 reveal that the proposed PRSS+FQDA approach outperforms the PRSS+HT and SOM approaches in terms of the number of vertical handoffs, handoff call dropping probability and GoS. In Fig. 11, the number of handoffs increases gradually as the mean arrival rate increases while PRSS+HT and SOM quite increase. Figure 12 shows the dropping probability comparison. The PRSS+FQDA
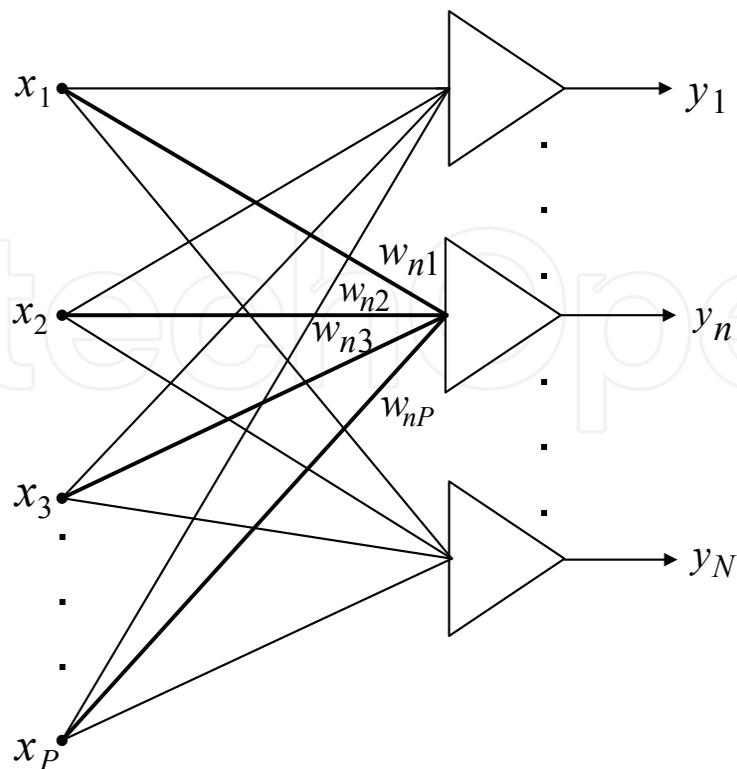
Fig. 7. SOM neural network

scheme yields the lower probability than other schemes which results in a fewest GoS as shown in Fig. 13.

In Figs. 14-16, we presented the results of the proposed PRSS+FQDA approach for the handoff numbers, handoff call dropping probability and GoS under various mobile velocities ranging from 5 to 30 m/s comparing to the other three vertical handoff algorithms, namely the PRSS+HT and SOM approaches. In Fig. 14, PRSS+FQDA yields the fewest vertical handoffs under various velocities but PRSS+HT yields the most vertical handoffs. As the velocity increases, the numbers of vertical handoffs of all approaches also increase. However, the impact of velocity to PRSS+FQDA is less than PRSS+HT and SOM. The handoff call dropping probability of the different approaches are investigated in Fig. 15. PRSS+FQDA has the lowest dropping probabilities and gently increases as the velocity increases while the other three methods obviously increase. Finally, the GoS versus mobile velocity of all approaches are shown in Fig. 16. The proposed PRSS+FQDA approach achieves low GoS although the mobile is moving in high speed. PRSS+HT and SOM generate higher GoS and proportionally vary to the velocity.

8. Conclusions

This paper has proposed a predictive RSS and fuzzy logic based network selection for vertical handoff in heterogeneous wireless networks. The RSS predicted by back propagation neural network is beneficial to avoid dropping calls if it predictes a mobile is moving away from the monitored wireless network. In additional to the RSS metric, the residence time in the target network is predicted which is taken into account for handoff trigger. The prediction period is calculated by the adaptive dwell time. For nonreal time service, the handoff policy is to attempt to use services of WLAN/WiMAX as long as possible. Meanwhile, the handoff
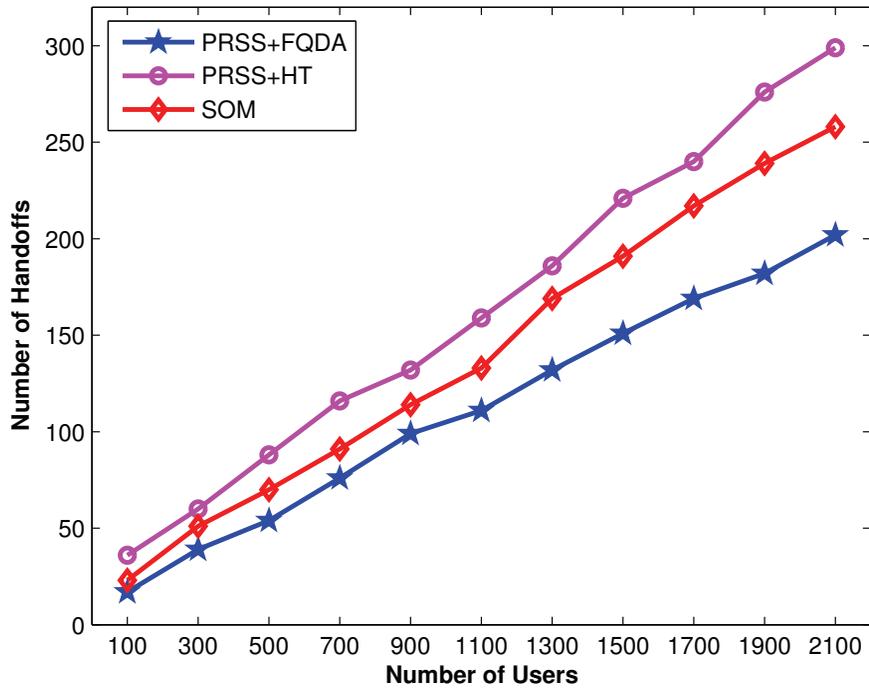
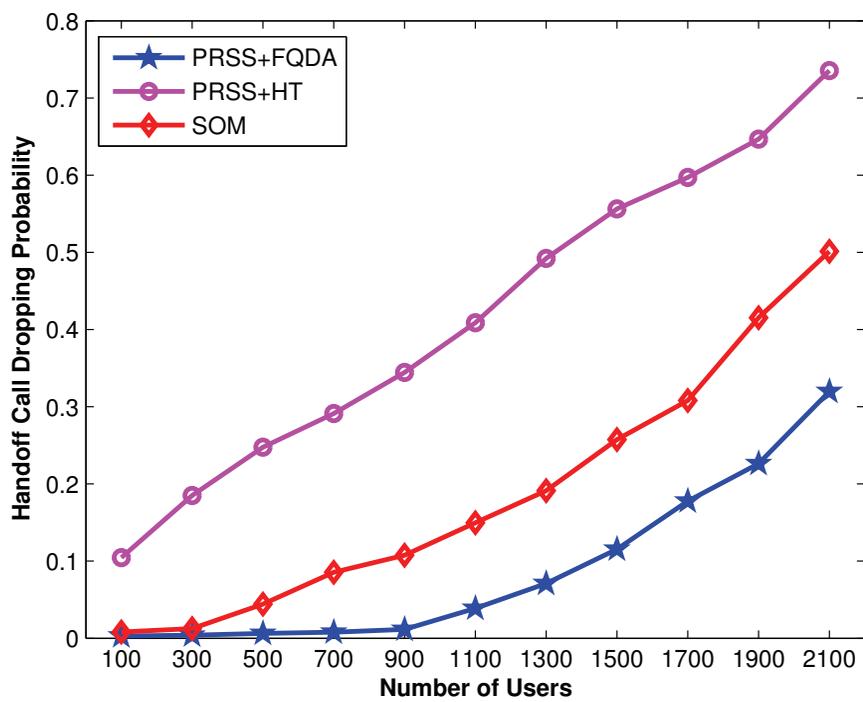Fig. 8. Number of handoffs versus numbers of users (Arrival rate = 3 sec)

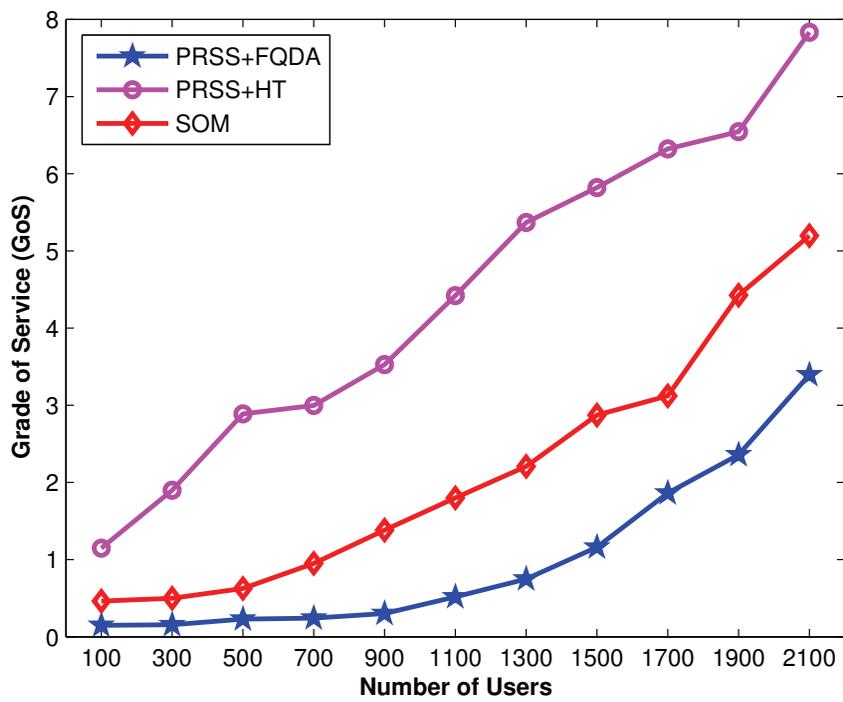Fig. 9. Handoff call dropping probability versus numbers of users (Arrival rate = 3 sec)

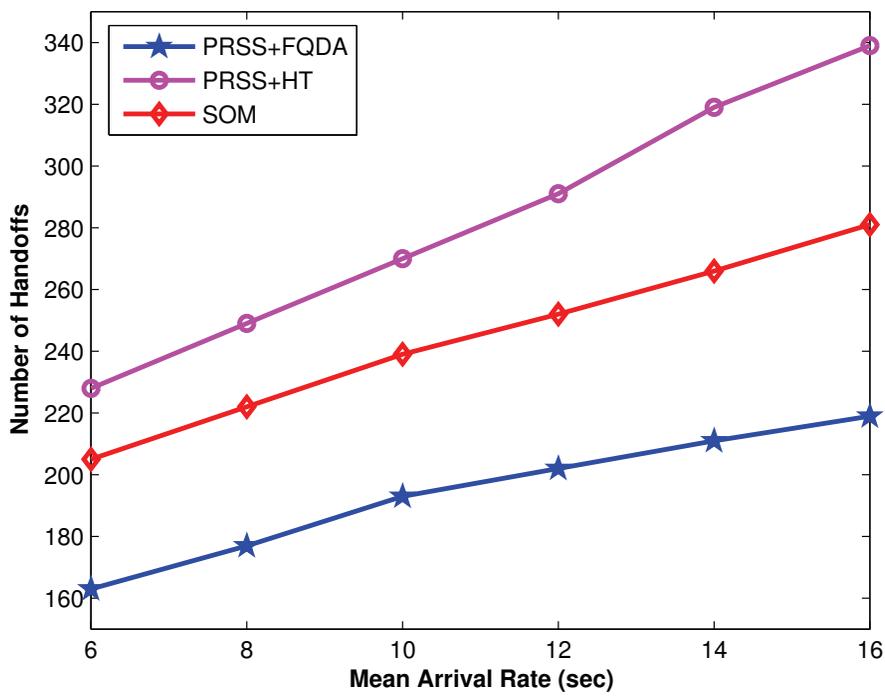Fig. 10. GoS versus numbers of users (Arrival rate = 3 sec)

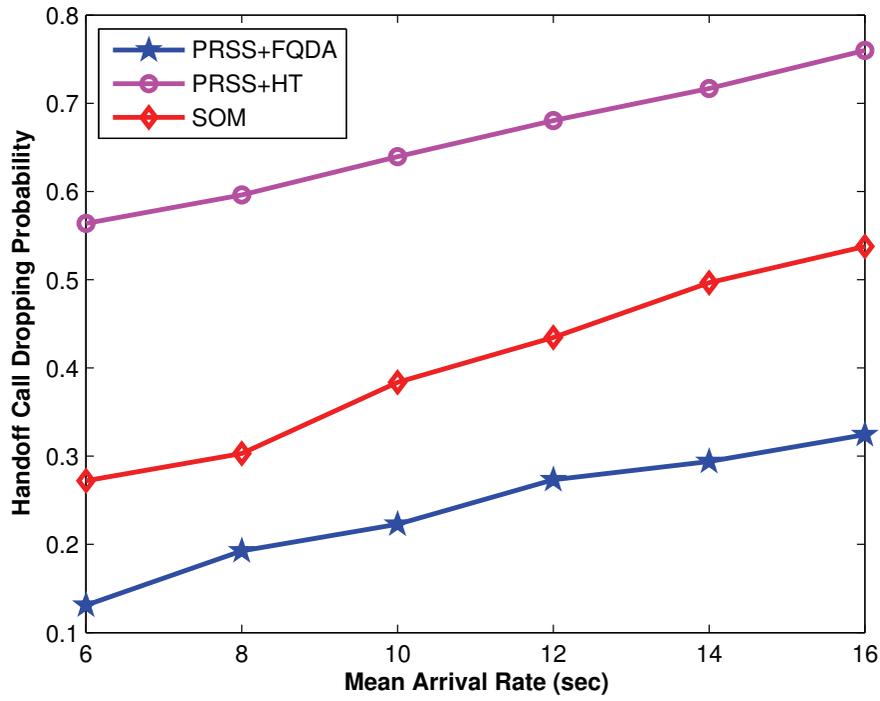Fig. 11. Number of handoffs versus mean arrival rates (Number of users = 1,500)

Fig. 12. Handoff call dropping probability versus mean arrival rates (Number of users = 1,500)
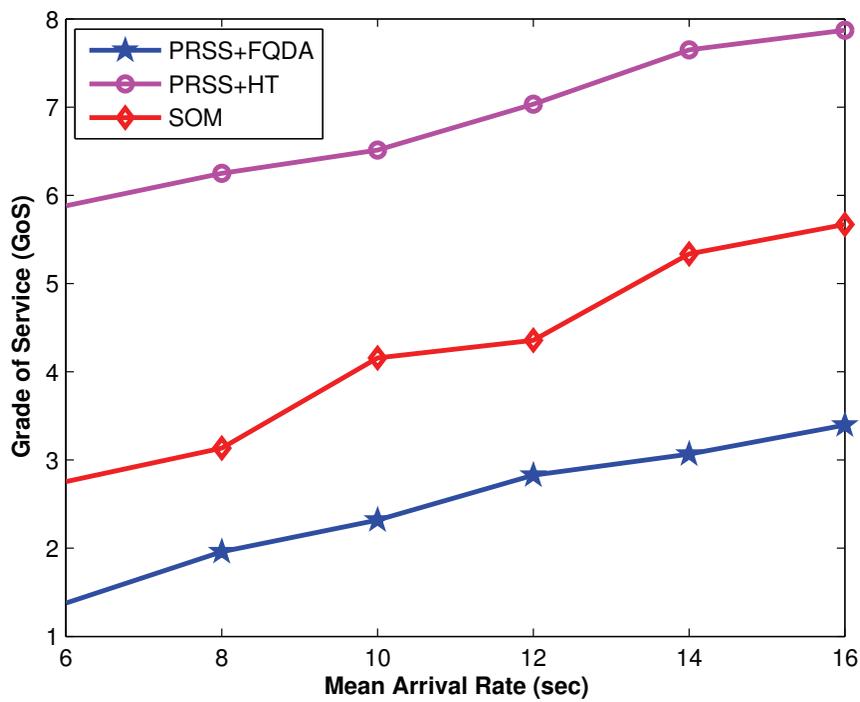

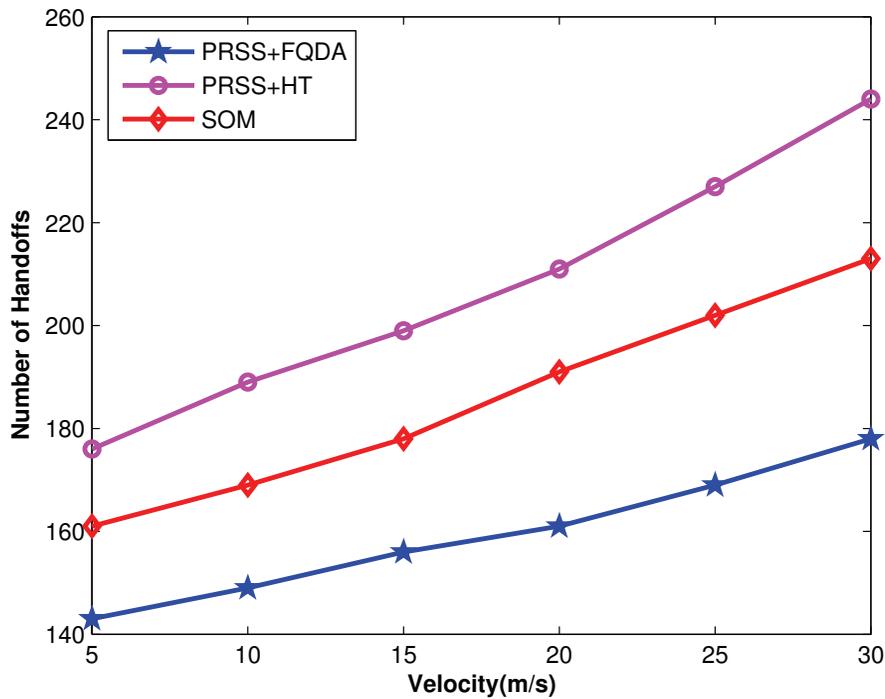Fig. 13. GoS versus mean arrival rates (Number of users = 1,500)

Fig. 14. Number of handoffs versus mobile velocity (Number of users = 1,500 and Arrival rate = 3sec)
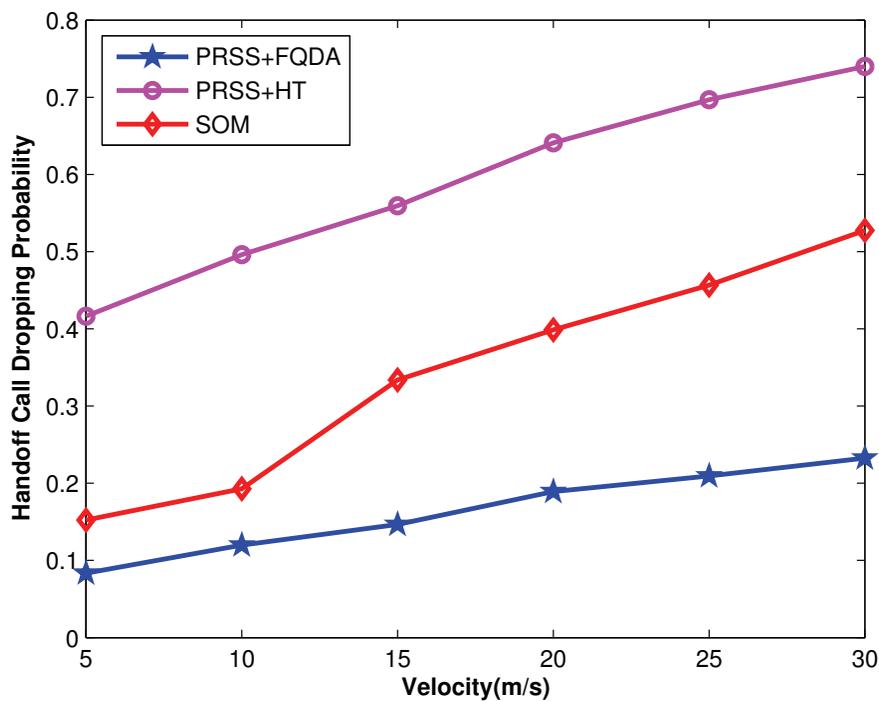
Fig. 15. Handoff call dropping probability versus mobile velocity (Number of users = 1,500 and Arrival rate = 3sec)
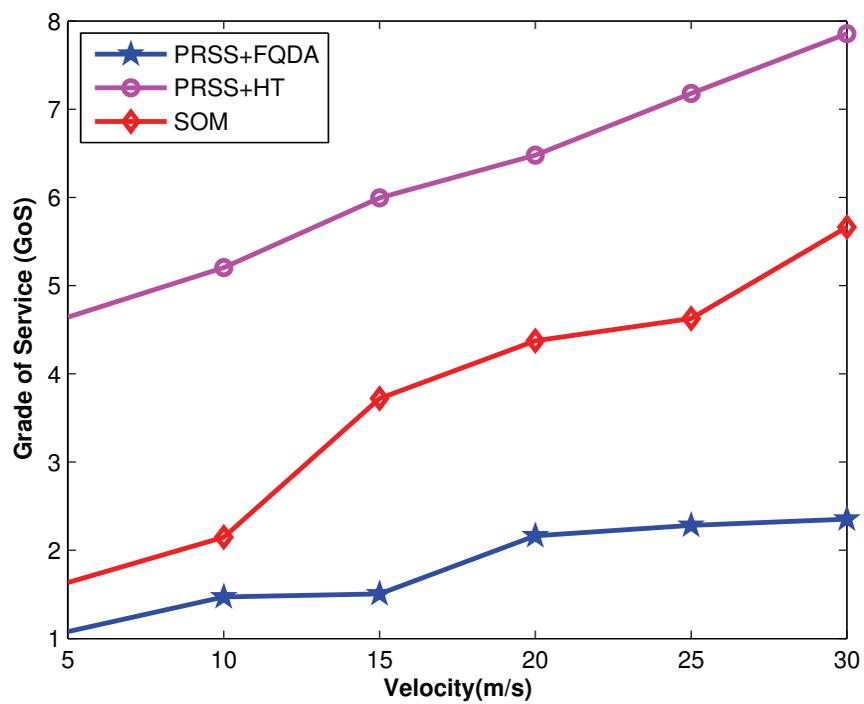
Fig. 16. GoS versus mobile velocity (Number of users = 1,500 and Arrival rate = 3sec)

policy of real time service is to have small delay. Merit function evaluating network conditions and user preference is used as the handoff criteria to determine candidate networks. Fuzzy logic using quantitative decision algorithm makes a final decision to select the optimal target network with the largest QDV. The proposed approach outperforms other approaches in number of vertical handoffs and call dropping probability and GoS.

9. Acknowledgments

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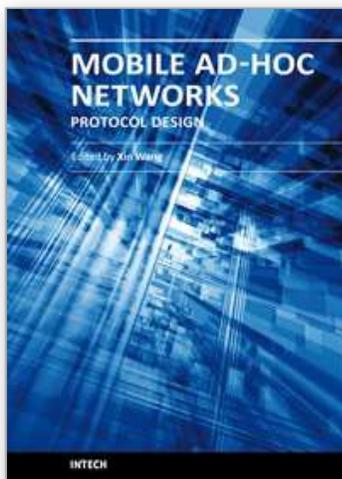
Mobile Ad-Hoc Networks: Protocol Design

Edited by Prof. Xin Wang

Being infrastructure-less and without central administration control, wireless ad-hoc networking is playing a more and more important role in extending the coverage of traditional wireless infrastructure (cellular networks, wireless LAN, etc). This book includes state-of-the-art techniques and solutions for wireless ad-hoc networks. It focuses on the following topics in ad-hoc networks: quality-of-service and video communication, routing protocol and cross-layer design. A few interesting problems about security and delay-tolerant networks are also discussed. This book is targeted to provide network engineers and researchers with design guidelines for large scale wireless ad hoc networks.

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