A Probabilistic Analysis of Network Selection Strategy for Heterogeneous Wireless Network

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Abstract—Next generation wireless networks will integrate multiple radio access technologies (RAT) to provide seamless connectivity to mobile users. Unified network selection can be achieved through a vertical handover (VHO) in which connection can be handed over among different RAT. In the existing literature, different kinds of network selection algorithms have been proposed to select the optimal network in heterogeneous wireless environment. But, uncertainty associated with network selection process is not yet modeled. Usually dynamics of network selection occur due to diverse characteristics of networks and also dynamic behavior of mobile users. These dynamic factors cause the variation in the utility and price offered by the network. In this paper, the impact of variation in the utility and price on the network selection and transition probabilities is analyzed through Markov model. The network level quality of service (QoS) is evaluated using new call blocking and hand off call dropping probabilities in terms of steady state probabilities.

Index Terms— Heterogeneous wireless environment, quality of service (QoS), universal mobile telecommunications system (UMTS) , utility function, steady state probabilities , transition probabilities and wireless local area network (WLAN).

1 Introduction

The ultimate aim of the network selection algorithm is to select the best target network in order to ensure the service with better QoS at the lowest price. Thus the network selection behavior of user's needs to be analyzed in terms of dynamic characteristics of networks and users. Dynamics of network selection in heterogeneous environment needs to be considered due to the following constraints.

1.1 Dynamic Behavior Of User

Different applications demand diverse QoS requirements, which results in the dynamics of network selection. Hence, selecting the optimal network corresponding to the dynamics of user behavior may incur frequent handovers. The tradeoff is required between dynamics of user behavior and network selection process.

1.2 VHO Cost

Dynamics of network selection may increase the handoff cost in terms of signaling overhead, energy and delay.

1.3 Dynamic Wireless Environment

Due to diverse characteristics of channel conditions and network performance, network selection process is uncertain to the mobile users.

Thus the overall network selection dynamics can be described as a stochastic process as it changes over time in a probabilistic manner. Due to dynamics of the decision metrics, there is a need to take only the most relevant metrics into account to provide the best network dynamically to the user. In [1] multicriteria optimization technique was presented to provide complete solution for seamless connectivity in heterogeneous environment based on network conditions, application level QoS, mobile terminal (MT) battery level and user preference. But, mobility model was not considered. When the MT is moving with velocity, it is necessary to find out how much time the MT will stay in the target network. If the estimated residence time of the network is less than the threshold, it requires more number of handovers to complete the ongoing service. Residence time of the network is estimated using velocity and mobility pattern of the user. But, the probability of moving in/out of the network and uncertainty about the decision metrics was not addressed. VHO decision making based on time varying attributes always face the problem of uncertainty associated with the network selection. The impact of variation in decision metrics on the dynamics of network selection can be described through state transition probability using Markov model. The major contribution of the paper is

1) To study the impact of utility and price offered by the network on the probability of selecting the target network.

2) To derive the state transition and steady state network selection probabilities by considering the utility, mobility and service model.

3) To analyze the consistency level of network selection and the network level QoS using the state transition model.

To attain network, service and application convergence, next generation networks must be designed in such a way that all the functions must work independent of characteristics of networks. Thus, the service providers can render their service to the users more efficiently with required throughput needed to support the fluctuating traffic demand generated by mobile users.

2 Related Work

Amali et.al [1] proposed Multicriteria based network selection algorithm to provide solution for seamless application QoS and user preference. Racha Ben Ali et.al [2] presented the impact of VHO rate on the network level performance such as call blocking probability under different

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mobility scenarios. In [3] the performance of integration of cellular & WLAN and dynamics of network selection was analyzed based only on decision metrics. But, the concept of competition among users and network was not addressed for network selection process. Dusit Niyato et.al [4] presented the dynamic evolutionary game to model the dynamic of network selection and user mobility in heterogeneous environment. Reinforcement learning algorithm also proposed to learn the performance of different networks. Thus, it select best suitable network based in the QoS requirement of application. In practice, user discovers the networks with asymmetric prices and QoS. Uncertainty associated with decision making varies with time. In [5] Markov model is used to model the uncertainty present in the network selection and Bayesian price competition game is also proposed to investigate the impact of increased competition on the overall efficiency. In addition to the QoS related decision metrics used in conventional network selection, users QoE is used in [6] to provide network selection dynamic environment. In [7] provides the analysis of network selection problem associated with dynamic demand, environment and dynamic network characteristics. Online network selection algorithm is also proposed to offer optimal network to the mobile user by providing optimization between QoS and network handoff cost. In [8] mathematical model describing the optimization, complexity and performance in heterogeneous environment are discussed. In [9] Enhanced Media Independent Handover Function (MIHF) is proposed to provide complete information about link layer and application layer in order to maximize the end user satisfaction.

3 System Model

Consider the integration of complementary RAT such as Universal Mobile Telecommunications System (UMTS) based cellular network and IEEE 802.11 based wireless local area network (WLAN) as shown in Fig.1 to enjoy the diverse range of services with better QoS, lowest price and seamless roaming. Let's consider WLAN as network 1 and UMTS as network 2 i.e. $i \in \{1, 2\}$. The method of modeling users through utility, mobility and service model are considered in the next subsections.

3.1 Utility Model

Considering the time varying characteristics of networks, different user requirements and mobility characteristics may select different networks. Thus, the networks in the coverage area have to be evaluated dynamically using appropriate utility function. Sigmoid based utility function is used to model the elasticity of applications and also to provide tradeoff between user demand and VHO rate. The degree of user sensitivity to QoS parameters for a particular service should be taken in to account in the utility calculation for network selection mechanism. The QoS parameters that can be considered for utility calculation are data rate, delay, energy consumption and cost.

The elementary utilities of QoS parameters are calculated using sigmoidal function [1] given by (1) with threshold value(x_m), lower (x_l) and upper(x_U) limits.

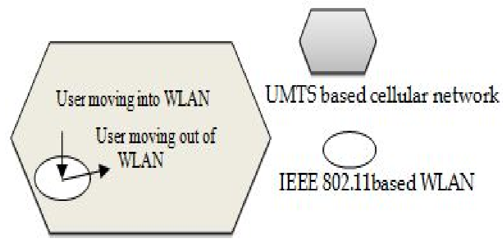

Fig.1. Heterogeneous wireless environment

$$u(x) = \begin{cases} 0 & x \le x_l \\ \dfrac{\left(\dfrac{x - x_l}{x_m - x_l}\right)^{\zeta}}{1 + \left(\dfrac{x - x_l}{x_m - x_l}\right)^{\zeta}} & x_l \le x \le x_m \\ 1 - \dfrac{\left(\dfrac{x_u - x}{x_u - x_m}\right)^{\zeta}}{1 + \left(\dfrac{x_u - x}{x_u - x_m}\right)^{\zeta}} & x_m < x \le x_u \\ 1 & x > x_u \end{cases} \quad (1)$$

Where, x represents the decision metrics considered for network evaluation. ζ determines the user sensitivity to the variation of network characteristics. The overall utility function is calculated for each network using multiplicative weighted utility function given by,

$$u_i = \prod_{k=1}^{n} \left(u_k(x_k)\right)^{w_k} \quad i \in \{1, 2\} \quad (2)$$

Where, wk is the weight values assigned according to the user preference and dynamic user demands. In practice, network compete each other based on price and utility offered by the network. Users pay minimum amount to connect with WLAN with no guaranteed QoS. But, cellular network offers better QoS with high cost. Thus, the asymmetry between utility and price pose remarkable change on the probability of connecting to a network.

3.2 Mobility And Service Model

A probabilistic based mobility model is considered for the user moving across the integration of UMTS and WLAN. The probability of users present in the WLAN area is denoted by P_r^{μ}. Hence, $1 - P_r^{\mu}$ corresponds to the probability of user residing outside the WLAN coverage. P_{out}^{μ} is the probability of user exiting the WLAN coverage. Under equilibrium conditions, the average number of users entering in to the WLAN area will be equal to the average number of users exiting the WLAN area. Thus, the probability of a user moving in to the WLAN area denoted by

$$P_{in}^{\mu} = \frac{P_r^{\mu} P_{out}^{\mu}}{1 - P_r^{\mu}} \quad (3)$$

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New calls arrive to the cellular network in a given time interval follow a Poisson distribution with mean arrival rate λ_n. The call service time is exponentially distributed with a mean of $\frac{1}{\mu}$. Hence the call completion probability is given by

$$P_{end} = P(T_{call} \leq T_{th}) \tag{4}$$

Where, T_{th} is the time interval for the user state transition. Considering exponentially distributed inter arrival time with a mean of $\frac{1}{\lambda_n}$, the new call arrival probability is given byP_{new}. In the following analysis, it is assumed that utility and service cost offered by the network and the probability associated with user mobility and service model are known.

4 Probability Based Network Selection Strategy

The acceptance probability or user satisfaction degree has been widely used in the network selection problem to analyze whether a user is convinced with the network selected using multicriteria based network selection algorithm. User satisfaction degree measures how much the user is satisfied with the perceived utility (u) and cost (c) offered by the network 'i'. It can be modeled as [10]

$$A_i(u, c) = 1 - \exp(-K\, u^{\mu}(c_i)^{-\varepsilon}) \tag{5}$$

Where, μ>0 and ϵ >0 control the sensitivity to utility and cost respectively and K is a positive constant representing the satisfaction reference value. Utility (U) is calculated using attributes such as data rate, delay etc. In the following section user preference is assumed to be equally sensitive to utility and service cost. The acceptance probability can indeed be used as a network selection probability in the presence of single network or idle state. However network transition from network i to j in the heterogeneous environment can be modeled using transition and steady state probabilities.

4.1 State Transition Model

Network transition from i to j occurs only if $u_i \geq u_j$ and $P_i \leq P_j$. It ensures that the user always be connected to the network with more utility at lowest cost thus the probability of selecting the suitable network should be equal to the user satisfaction probability of the network, when the user is in idle state'0'. It can be expressed as

$$S_{0i} = S_i \tag{6}$$

Where, S_i= $A_i(U, c)$

Then, the network transition occurs when the user is not satisfied with the connected network and also user mobility corresponding transition probability must be linear function of network selection probability and handover cost. It is obtained as

$$S_{ij} = \Upsilon_{ij} S_{0j} \tag{7}$$

Where, Υ_{ij} is the handover cost.

For the given system model of Fig.1, user can be in one of the following states as shown in Fig.2:

1) State 0: The user is idle condition and there is no call in progress.

2) State 1: The user is outside the WLAN and connected with UMTS.

3) State 2: The user is inside the WLAN and connected with UMTS.

4) State 3: The user is inside the WLAN and connected with WLAN.

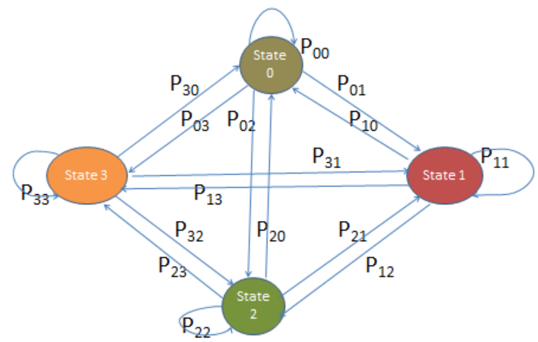

Fig. 2. State transition diagram.

The state transition probability matrix is constructed using the above 4 state conditions and given by

$$P = \begin{bmatrix} P_{00} & P_{01} & P_{02} & P_{03} \\ P_{10} & P_{11} & P_{12} & P_{13} \\ P_{20} & P_{21} & P_{22} & P_{23} \\ P_{30} & P_{31} & P_{32} & P_{33} \end{bmatrix} \tag{8}$$

Where, P_{01} represents the state transition from state 0 to state1 and also include three events. i) The user is outside the WLAN. ii) Connected to UMTS. iii) A new call is originated. Whenever new call arrives, the probability of connecting with WLAN and UMTS are given by P_{03} , P_{02} and P_{01} using equations (5), (6) & (8).

$$P_{01} = S_2(1 - P_r^{\mu})P_{new} \tag{9}$$

Similarly P_{02} and $P_{03}$is given by

$$P_{02} = (1 - S_1)S_2 P_r^{\mu} P_{new} \tag{10}$$

$$P_{03} = S_1 P_r^{\mu} P_{new} \tag{11}$$

The probability of remaining connected to the network is given by

$$P_{11} = \beta_2 S_2 (1 - P_r^{\mu})(1 - P_{end}) \tag{12}$$

$$P_{33} = \beta_1 (1 - S_2) S_1 P_r^{\mu} (1 - P_{end}) \tag{13}$$

$$P_{22} = \beta_2 (1 - S_1) S_2 P_r^{\mu} (1 - P_{end}) \tag{14}$$

Where, β_1 and β_2 are scaling constants.

There is a probability that a user moving into the WLAN and connected with either WLAN or UMTS. The corresponding probability are given by

$$P_{12} = (1 - S_1) S_2 P_{in}^{\mu} (1 - P_{end}) \tag{15}$$

$$P_{13} = \Upsilon_{21} (1 - S_2) S_1 P_{in}^{\mu} (1 - P_{end}) \tag{16}$$

There is a probability that a user is moving out of the WLAN and connected with UMTS. It can be expressed as

$$P_{21} = P_{31} = \beta_2 S_2 P_{out}^{\mu} (1 - P_{end}) \tag{17}$$

When the user is in the WLAN coverage, the state transition probability are given by P_{23}andP_{32}.

$$P_{23} = \Upsilon_{21}(1 - S_2)S_1 P_r^{\mu} (1 - P_{end}) \quad (18)$$

$$P_{32} = \Upsilon_{12}(1 - S_1)S_2 P_r^{\mu} (1 - P_{end}) \quad (19)$$

Where, S_1 and S_2 represents the network selection probability of WLAN and UMTS respectively. After calculating all the P_{ij}, we can obtain P_{i0} $\forall$ i ∈{0, 1, 2, 3} using the Markovian property that sum of element of each row of transition matrix is unity.

$$\sum_{j=0}^{3} P_{ij} = 1 \Rightarrow P_{i0} = 1 - \sum_{j=1}^{3} P_{ij} \quad (20)$$

4.2. Steady State Network Selection Probability

Steady state probability is defined as the long term probability of being in a particular state. Given that π_i represent the steady state probability of being in states i ∈{0, 1, 2, 3}. It can be expressed as a row vector π.

$$\pi = [\pi_0 \ \ \pi_1 \ \ \pi_2 \ \ \pi_3] \quad (21)$$

Markov chain under consideration is time homogeneous. Thus steady state probability should sum to unity.

$$\pi_0 + \pi_1 + \pi_2 + \pi_3 = 1 \quad (22)$$

The steady state probability vector is the left eigenvector for the state transition probability matrix corresponding to eigenvalue 1. It can be expressed as

$$\pi P = \pi \quad (23)$$

$$[\pi_0 \ \ \pi_1 \ \ \pi_2 \ \ \pi_3] \begin{bmatrix} P_{00} & P_{01} & P_{02} & P_{03} \\ P_{10} & P_{11} & P_{12} & P_{13} \\ P_{20} & P_{21} & P_{22} & P_{23} \\ P_{30} & P_{31} & P_{32} & P_{33} \end{bmatrix} = [\pi_0 \ \ \pi_1 \ \ \pi_2 \ \ \pi_3]$$

By solving the above matrix we can obtain following equation

$$P_{01}\pi_0 + (P_{11} - 1)\pi_1 + P_{21}\pi_2 + P_{31}\pi_3 = 0 \quad (24)$$

$$P_{02}\pi_0 + P_{12}\pi_1 + (P_{22} - 1)\pi_2 + P_{32}\pi_3 = 0 \quad (25)$$

$$P_{03}\pi_0 + P_{13}\pi_1 + P_{23}\pi_2 + (P_{33} - 1)\pi_3 = 0 \quad (26)$$

The equations 22, 24, 25 and 26 can be constructed in matrix form to obtain the steady state probability πi.

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ P_{01} & (P_{11} - 1) & P_{21} & P_{31} \\ P_{03} & P_{12} & (P_{22} - 1) & P_{32} \\ P_{03} & P_{13} & P_{23} & (P_{33} - 1) \end{bmatrix} \begin{bmatrix} \pi_0 \\ \pi_1 \\ \pi_2 \\ \pi_3 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (27)$$

Thus, steady state probabilities are obtained in terms of network selection and state transition probability.

5 Network Level Analysis

In the previous sections, dynamics of user network selection behavior is described using probability based mobility model and then modeled using state transition diagram. In this section network level QoS metrics such as new call blocking and hand off call dropping probability are analyzed using steady state probability π_i.

Assume that N_1 and N_2 are the number of channels in the WLAN and cellular network respectively. n_1 & n_2 are the number of users in the WLAN and UMTS respectively. N_h is the channels reserved to prioritize the hand off calls from WLAN to cellular network. n_t is the total number of calls/users in the system. For the given system model, cellular network accepts both new and hand off calls only if $n_1 < N_{th.}$ where, $N_{th} = N_2 - N_h$. A new call is blocked by cellular network if at least N_{th} channels are already occupied. It can be denoted by P_2^B.

$$P_2^B = \sum_{n_2=N_{th}}^{N_2} \binom{n_t}{n_2} (\pi_1 + \pi_2)^{n_2} (1 - (\pi_1 + \pi_2))^{n_t - n_2} \quad (28)$$

The hand off call dropping probability of cellular network is the probability that all the N_2 channels are occupied. New calls cannot occupy N_h channels but hand off calls can occupy N_h channels. It can be denoted by P_2^D.

$$P_2^D = \binom{n_t}{N_2} (\pi_1 + \pi_2)^{N_2} (1 - (\pi_1 + \pi_2))^{n_t - N_2} \quad (29)$$

A new call is block by WLAN only if N_1 channels are connected. Since there are no channels reserved for handoff calls. New call blocking probability is equal to the handoff call dropping probability.

$$P_1^B = P_1^D = \binom{n_t}{N_1} (\pi_3)^{N_1} (1 - \pi_3)^{n_t - N_1} \quad (30)$$

In numerical analysis, network level parameters are analyzed under the assumption that the total number of calls/users in the system is more than the maximum number of channels available in the networks.

6 Numerical Results And Discussion

In this section, the performance of the proposed scheme is analyzed numerically using MATLAB. In network selection algorithm, utility offered by the network is calculated using the decision metrics such as data rate, delay and energy conception. The best suitable network is selected based on the values of utility and cost of service according to the application QoS and user performance. Parameters of simulation are as follows: N_1=20, N_2 = 60, N_h = 6, n_t =100, N_{th} =54, $P_r^{\mu} = 0.5$, P_{out}^{μ} =0.1, P_{new}=0.4, Υ_{ij} = ε = μ = K = β = 1.

The utility of the network is calculated using (2) for the network parameters considered for the given system model. Dynamics of the network selection process occurs due to uncertainty associated with decision metrics in heterogeneous wireless environment. This kind of dynamicity is described using steady state probabilities. To analyze the dynamics of the network selection process, normalized values of utility and service cost are directly considered.

To show the impact of utility and cost offered by the network on the steady state probability of connecting to network, utility and service cost of UMTS network is kept constant at u_2=0.8 and c_2=0.6. The steady state probability of connecting to WLAN is plotted with variation in the utility of the network for various values of service cost. It is observed that when $u_1 < u_2$ and $c_1 < c_2$, network selection probability of network is slightly higher than UMTS. An increase in the u_1 or decrease in c_1 causes an increase in the steady state probability of WLAN. When $u_1 < u_2$ & $c_1 > c_2$ UMTS dominates the WLAN network. Thus the probability of selecting the UMTS is very much greater than WLAN. When $u_1 > u_2$ & $c_1 < c_2$, steady state probability π_3 become high due to domination of WLAN network as shown in Fig. 3.

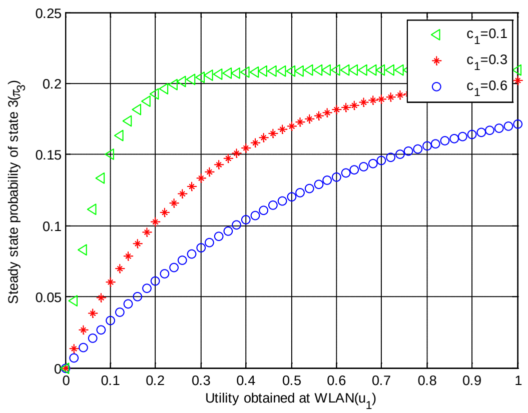

Fig.3. Variation of steady state probability of state 3(π_3) with utility (u_1) obtained for various cost at WLAN.

In Fig.4 the variation of the new call blocking probability at UMTS with the probability of moving out of WLAN coverage is shown for various values of utility and service cost. Given c_2 =0.6 and u_2 =0.8 when u_1=0.6 and c_1=0.9 UMTS dominates WLAN. Thus, the probability of selecting the UMTS (S_2) is higher than the network selection probability of WLAN (S_1). This is the reason for an increase of P_2^B in the UMTS. For the scenario with u_1=0.8 & c_1=0.3, WLAN becomes more suitable network than UMTS. This condition can reduce the number of users in the UMTS network and also new call blocking probability. It is inferred that dynamics of user behavior causes the dynamic network selections which in turn affects the network level QoS such as new call blocking probability.

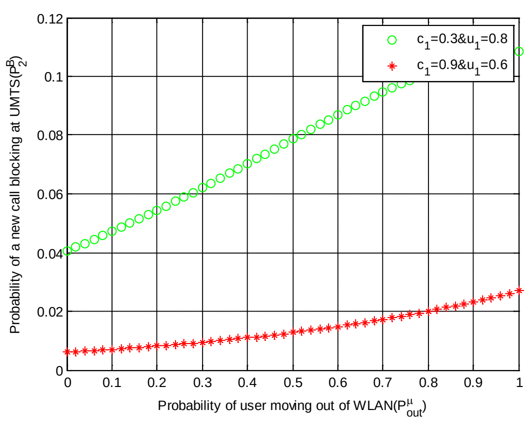

Fig. 4. Variation of new call blocking probability (P_2^B) with probability of user moving out of WLAN (P_{out}^{μ}) obtained for various cost and utility.

In Fig.5 the variation pattern is same as that of P_2^B except that the rate of increase of P_2^B is high compared to P_2^D. This is due to the fact that N_h channels are reserved for hand off calls in the UMTS. For the scenario with high hand off rate, the value of Nth can be adjusted dynamically in order to minimize the P_2^D . It is observed that dynamics of network selection affects the steady state probability of user. The variation of steady state probability degrades the network level QoS in heterogeneous environment.

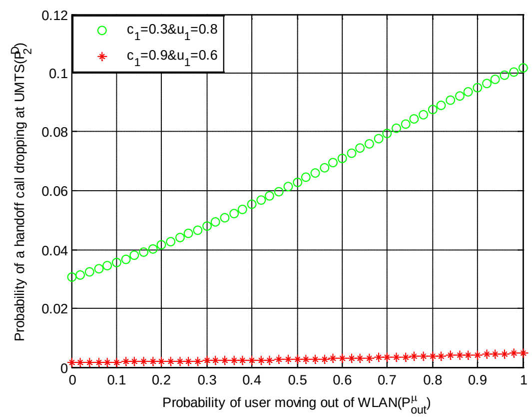

Fig.5. Variation of handoff call dropping probability (P_2^D) with probability of user moving out of WLAN (P_{out}^{μ}) obtained for various cost and utility.

7 Conclusion

Network selection in heterogeneous wireless network always faces the problem of uncertainty associated with dynamic demands, environment and network selection. Thus, the dynamics of network selection can be described as stochastic process using probability based Markov model. The impact of variation in the utility and cost of service on the network selection probabilities and network transition probabilities is studied for the given system model. The overall network selection dynamics and the performance of the networks are analyzed through steady state probability. Network level performance is also analyzed through blocking and dropping probabilities based on steady state probabilities and total number of user in the system. For future work, network level QoS such as call dropping probability will be analyzed in terms of user level QoS such as packet loss rate (PLR) and delay.

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