

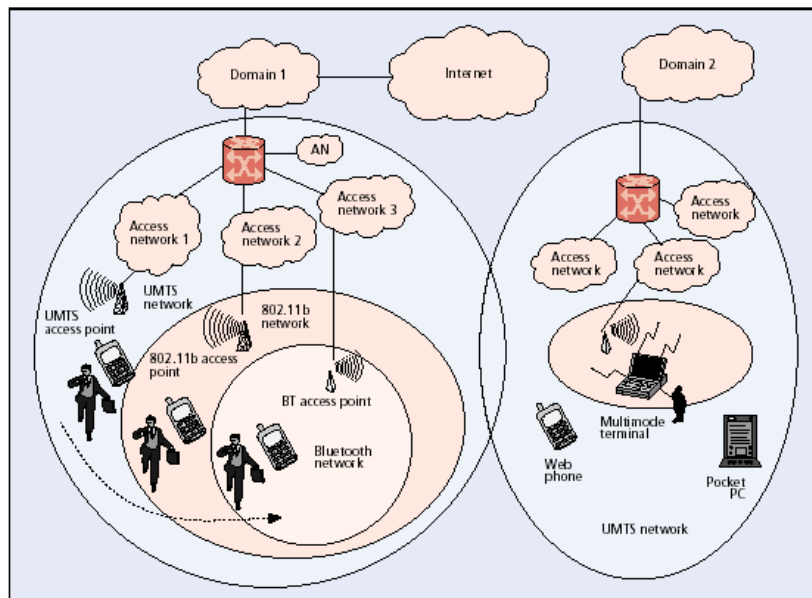
## **State of the Art: Admission Control and Mobility Management in Heterogeneous Wireless Networks**

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### **1. Introduction**

Future mobile networks will not consist simply of one radio access technology such as WCDMA (wideband code division multiple access) or EDGE (enhanced data rate for GSM evolution), but will contain many different technologies. Seamless intersystem roaming across heterogeneous networks, as depicted in Figure 1, will be one of the main features in future generation mobile networks such as those envisaged in an integrated smart space environment. The motivation for heterogeneous networks arises from the fact that no one technology or service can provide ubiquitous coverage and continuous high QoS (quality of service) levels across multiple smart spaces. It will therefore be necessary for a mobile terminal to employ various points of attachment to maintain connectivity to a corresponding node at all times. Many wide area wireless network technologies are emerging. WCDMA is designed to meet the future requirements of third generation wireless communication services with data rates up to 2Mbps. UMTS (Universal Mobile Telecommunications System) will be based on this radio access technology. Both packet and circuit switched services can be freely mixed, with variable bandwidth and delivered simultaneously to the same user with specific quality levels. GPRS (General Packet Radio System) is a packet data service within GSM allowing bit rates from 9 to more than 150kbps. The user will be charged for the amount of data that is transferred and not for the connection time. Satellite networks promise global coverage and total ubiquitous computing but with lower QoS constraints than its cellular counterparts, while WLAN provides high-speed data service (up to 11Mb/s with 802.11b and 54Mb/s with 802.11a/g) over a geographically small area. All these network technologies differ in bandwidth, latency, power consumption and cost. Mobile terminals in a smart space environment will seamlessly roam between these access networks so as to maintain minimum QoS contracts for different applications and support user preferences. Supporting this seamless mobility is seen as one of the key issues in resource management for heterogeneous wireless networks (Shiao-Li Tsao, 2002). With intersystem mobility, users will benefit from the different coverage and capacity characteristics of each network throughout the interconnected smart spaces. Low tier WLAN offers high bandwidth but with less mobility than a UMTS network which offers medium bandwidth but with greater mobility. Services carried by future generation mobile networks will demand varying QoS for both real-time and non real-time applications. It is only with efficient mobility management and sophisticated admission control algorithms that these QoS constraints can be met and maintained (Nokia CRRM, White Paper, 2001). In a network with a mixture of resources (a heterogeneous network) offering a mixture of different services, it will be vital to provide the optimum radio bearer for each service.

This paper presents a state of the art survey in resource management in heterogeneous networks, in particular, emphasis is given to admission control and mobility management between different access schemes both of which are critical in a heterogeneous network environment as they balance the load across networks while maintaining sufficient QoS for varying traffic types.



**Figure 1. Seamless vertical handover in a 4G environment (A. Misra 2002)**

## 2. Overview

Giving access to users as they roam between networks or within a single network is governed by an admission control scheme. Admission control enables a wireless network to carry the largest amount of traffic for a given amount of spectrum. It ensures that the QoS perceived by each user is above the minimum guaranteed. Admission control and mobility management strategies facilitate load balancing between heterogeneous networks - users can be forced to handover to another network to make way for users with more demanding bandwidth requirements and can thus prioritise users. It may be possible using an admission control algorithm to admit a user to multiple networks simultaneously and use multiple connections to deliver services to the user and thus achieve a higher QoS than that offered from a single network. Much work has been done on call admission control in homogeneous networks such as UMTS. Before admitting a new user, admission control needs to check that the admittance will not sacrifice the planned coverage area or the quality of the existing connections. In UMTS, admission control accepts or rejects a request to establish a radio access bearer in the radio access network based on the interference levels, as the capacity in UMTS is interference limited. The introduction of a new user increases the interference level to existing users as all connections share the same radio channel. SIR (Signal to Interference Ratio) values are periodically measured to determine the level of interference at each base station. The SIR is the ratio of the received signal strength to the total interference from all interfering mobiles.

The admission control algorithm is executed when a bearer is set up or modified. The admission control functionality can have a decentralised approach where information regarding neighbour cell loads can be obtained from an entity controlling those cells. The admission control algorithm estimates the load increase that the establishment of the bearer would cause in the radio network. This has to be estimated for both the uplink and downlink for asymmetrical traffic. The requesting bearer gains access only if both the uplink and downlink admission control admit it, otherwise it is rejected because of the

excessive interference that it would produce in the network. Proposed admission control schemes for WCDMA cellular systems will be discussed in a later section.

The admission control procedure across heterogeneous networks is much more complicated than in a homogeneous network such as that described above. If multiple networks are available to a user at any one time, then choosing the most optimal network for a particular service delivery and choosing the correct time to execute a vertical handover<sup>1</sup> to improve the QoS for all users are important factors. A mobility management system can be used to control the migration of users from one system to another. The user, network or both can govern the mobility management and admission control procedures. Giving total control to the user can result in network instability as users compete for network resources, while a network controlled system will ignore user preferences and QoS requirements. The most optimal mobility management and admission control scheme should encompass both aspects – mobile assisted call admission control and mobility management.

The mobility management system will have many parameters with which to make a vertical handover decision, such parameters should include:

- Signal Strength Measurements
- Bit Error Rates
- Perceived QoS and the QoS requirements for the current application
- Network Coverage
- Cost
- Battery Power requirements to implement the handover – powering up new interface
- User Preference – user wants to be connected to the cheapest network available regardless of offered QoS

The above parameter values come from both the network and the user and thus emphasises the need for the mobile assisted approach. The mobility management algorithm will process this information and decide which is the most optimal network from those available and when is the correct time to initiate a handover. Schemes based on Policy (Helen J. Wang, 1999), Fuzzy Logic (P.M.L.Chan 2001a, P.M.L.Chan 2001b) and Neural Networks (J. Makela 2000) have been proposed and will be discussed in the next section.

The chosen network will admit the user if resources are available or may force a current user to handover to another network to make way for the incoming connection. Checking resource availability in GSM/GPRS is a straightforward procedure as network access is based on FDMA/TDMA. If the requested timeslots are available the service can be delivered at the requested data rate. However, capacity in UMTS is interference limited. UMTS utilises WCDMA on the air interface, users are separated using different spreading codes with all users sharing the same bandwidth. Admitting another user will increase the overall interference level for all users in the reference and neighbour cells and therefore reduces the average SIR at the receiving base station. Users requiring high data rates will demand a high SIR level. It is important therefore to accurately control access in a UMTS network. In a heterogeneous network environment, the mobility management system can move users from a UMTS network to make way for a high priority user in the event of high congestion. The next section will discuss state of the art proposals for mobility management and call admission control algorithms in heterogeneous networks using various techniques. The proposals are mainly concerned with handover

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<sup>1</sup> Vertical handover is the common term given to handovers between access networks

initiation and network selection. The proposals do not address the availability and reservation of resources in the destination network or the network controlled movement of users between networks to ensure the availability of capacity.

### 3. Analysis

This section will detail state of the art proposals for mobility management and admission control schemes in heterogeneous networks. Mobility management is primarily concerned with handover initiation and network selection. Admission control is inherently part of the handover execution stage and governs access to the chosen network. The state of the art in each of these areas will now be presented.

#### 3.1 Handover Initiation

Handover Initiation is the process of monitoring the current network connection, recognising the need for handover and subsequently initiating it. The criteria used will reflect the condition of the current network connection such as signal strength, the coverage area, bit error rate and perceived QoS. As outlined in (Reynolds, 2000), there are three main reasons to initiate a handover.

To service a user request. For example, a user currently participating in a multimedia call may request their QoS to be modified in such a way that the serving cell, code, technology, network is unable to service the request.

To service a system request. For example, to maintain an existing call or to maintain network policy regarding user access rights, guaranteed QoS to users, optimal network selection to serve user request etc.

To service a service provider request. For example, a service provider's preferred network over which to deliver a service may be time dependent.

The handover initiation algorithm needs to process many parameters and decide whether a handover to another system is required. In (P.M.L.Chan, 2001a) a handover initiation algorithm using Fuzzy Logic concepts is presented. The algorithm is separated into three different stages. In the first stage, data from the system is fed into a fuzzifier, to be converted into fuzzy sets. A fuzzy set is a set without a crisp, clearly defined boundary and therefore, has a varying degree of membership. The system data comprises of values defining QoS perceived by the user, network coverage, bit error rate and average signal strength measurements which are mapped into a membership value of a fuzzy set. In the second stage, a set of IF-THEN fuzzy rules is applied to the system. These rules are conditional statements that specify how the fuzzy system works. The following example taken from (P.M.L.Chan, 2001a) illustrates the concept.

IF signal strength is strong, AND QoS is good, AND Bit Error Rate is medium, AND Network Coverage is medium, THEN handover = NO

Other possible outcomes are, Yes, Possibly Yes, and Possibly No. A table is generated that shows the outcomes for all possible values of the input criteria. Each outcome is assigned a membership value based on the input criteria. The final stage of the algorithm is the defuzzification process where all outputs are aggregated to produce a single number representing the handover factor. Based on the final handover factor, a handover will be initiated or not.

Deciding the correct time to initiate a handover is an important part of mobility management in a heterogeneous network. For example, users may want to minimize the cost of being connected to a cellular data service and therefore want to maintain WLAN connectivity as long as possible. In (J. Makela 2000), a predictive inter technology handover algorithm is presented. Neural network based pattern classification using signal strength measurements are used for path identification. As a user moves away from a WLAN access point, the system recognises the migration path from trained samples and therefore knows the most optimal handover initiation time. This classification type handover algorithm will need prior knowledge of the radio environment so that the neural networks can be trained before system deployment. The author's argue, however, that this training can be conducted gradually while the system is on line.

A technique for handover initiation using neural networks is also presented in (Kaveh Pahlavan, 2000). A three-layer back propagation neural network used for pattern recognition (S. Haykin, 1999) is trained using received signal strength measurements and locations where handoffs should be made. In this way, the system requires knowledge of the received signal strength patterns at such locations. A simulation scenario is presented using four identical base stations (BS) in a micro cellular environment and a mobile host (MH), which is moving from the neighbourhood of BS<sub>1</sub> toward BS<sub>2</sub> along a direct path. It is assumed that all BSs can provide the same service to the MH. The neural network takes a number of power samples from each BS and using pattern recognition, selects the BS, which is most suitable, while minimizing handoff delay and ping-pong<sup>2</sup> effect. The output of the system is a control signal that is zero as long as the MH is closer to BS<sub>1</sub> and one whenever the MH is closer to BS<sub>2</sub>. As in (J. Makela 2000), the system requires prior knowledge of the radio environment and needs much configuration before deployment.

### **3.2 Network Selection**

The aim of the network selection stage is to select a network connection that can satisfy the requirements of the network provider and also the user, such as low cost, good signal strength, optimal bandwidth, low network latency and high reliability. In (P.M.L.Chan, 2001b) a fuzzy logic multiple objective decision making algorithm is presented. There are two stages to the handover decision. In the first stage a fuzzy ranking procedure is used to compare the performance of the different networks for a particular handover decision criterion. For example, when cost is considered, the network with the lowest cost will have the highest ranking for the cost criteria. The weighting of the criteria is then developed by obtaining a ratio scale for the criteria based upon a paired comparison of each criterion. In the second stage of the algorithm these weightings are applied to each criterion and the highest criterion value selected.

The chosen network will be the one corresponding to the highest ranking for that criterion. To evaluate the performance of the algorithm, three access segments are considered, GPRS, UMTS and a satellite system.

A policy controlled handover scheme between heterogeneous networks is presented in (Helen J. Wang, 1999). This scheme allows users to express policies on what is the best wireless system at any moment and makes tradeoffs among network characteristics and dynamics such as cost, performance, and power consumption. A network condition estimation scheme is used that periodically reports the available bandwidth at each network to the mobile host. A performance agent collects this information on current bandwidth usage at base stations and announces this information to its coverage area. Based on this

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<sup>2</sup> Excessive handovers between two base stations is commonly referred to as the ping-pong effect

information, policies are designed that achieve load balancing across different networks. The policy approach presented in this work uses a cost function to evaluate the performance offered by each network. The cost of using a network at a certain time is a function of several parameters, the bandwidth it can offer,  $B$ , the power consumption of using the network access device,  $P$  and the cost  $C$  of each network. Each parameter has an associated weight factor. The bandwidth parameter estimates the current network condition, while power consumption and cost are fixed budgets whose weightings must change to reflect battery power available and how much money the user has currently spent. If a user wants to be connected to the cheapest network at all times, then  $w_c$  should be set to 1 and 0 for the other weight values. When comparing two networks, their cost functions are evaluated and the one with the lowest cost value is selected. Periodically, the system re-calculates the cost function of each reachable network based on up to date parameters. A stability period is included to ensure a handoff is worthwhile for each mobile. The stability period is a function of  $T_{\text{makeup}}$ , which is defined as the time needed to make up the loss of money or data depending on the current policy due to handoff latency. If a user is likely to be in the range of a better network for  $T_{\text{makeup}} + \text{handoff latency}$ , then it is worthwhile to handoff. Experimentation is carried out with four networks: IBM Infrared LAN, Lucent WaveLAN, the Metricom Ricochet network and GSM.

### 3.3 Handover Execution

The objective of the handover execution stage is to change cell, code technology, or network conforming to the details resolved during the decision phase. As outlined in (Reynolds, 2000), handover execution across heterogeneous networks involves the following issues.

1. Connection Changes. Changing radio links often means changing radio access nodes. New connections need to be set up and superfluous connections released.
2. Switching and bridging. If data is to be transmitted on two connections (packet duplication) or if data coming on two connections is to be combined on one connection, a bridge connection is required. Bridge connections are used, for instance, to prevent loss of data. Once this feature is no longer needed the bridge is released.
3. Combining and multicasting. In the case where macro diversity is supported by the layer network involved, connections are added to and released from multi-casting and combining points. In this case, adding a connection does not imply releasing another.
4. Re-routing. Handover may imply re-routing of connections through the fixed network, even outside the access network that is currently involved.
5. Control point transfer. If a user moves from one domain to another, it could be required to transfer control.
6. Security functions. Handover often requires the transfer of security keys and authentication.

To support seamless mobility in a heterogeneous environment, the mobility management entity will be required to locate roaming terminals for call delivery and maintain connections with terminals that change their point of attachment. Fast handoff with minimal packet loss is an important characteristic in any mobility management architecture.

IP will be the common network layer protocol in future mobile networks as outlined by A. Sanmateu et al (2002):

“... IP technology has emerged as a natural means of initiating network convergence and the all IP paradigm has become the implicit assumption for most studies on the next generation architecture design”.

With this view of an all IP core network, Mobile IP is the common approach for macro mobility management between access segments (Shiao-Li Tsao 2002, A. Sanmateu 2002). Cellular IP and hierarchical network structure using Mobile IP with packet buffering and redirection have been proposed for micro mobility within an access network (A. Misra 2002, Andras G. Valko 1999, Jon Chung Shien Wu 2001, Chen Lin Tan 1999).

### 3.3.1 Macro Mobility

The movement of a mobile host between access networks is known as macro mobility. Mobile IP has been widely proposed in the implementation of macro mobility. In an IP network, the IP address is usually representative of the location of the IP node. As the mobile node changes its point of attachment, the association between the mobile's identity and location is lost. Mobile IP solves this problem by registering the address of a foreign agent (FA) in which the mobile node is roaming at the home agent (HA) in the mobile's home network. The address of the FA is known as the Care of Address (CoA). Any packets received at the HA addressed for the mobile node are “tunnelled” to the FA and delivered to the mobile node. As mobiles move to a new area covered by a new FA, the new CoA has to be re-registered at the HA. Figure 2 shows the message exchange for UMTS/WLAN handover using Mobile IP. Mobile IP introduces latency in the handover procedure and is not appropriate to handle seamless handoffs for real time traffic. To reduce the handover latency, an enhancement to Mobile IP is proposed, in (A. Sanmateu 2002). In this the radio channel signal quality is used to predict a handover, therefore the HA registration procedure can take place prior to the handover and thus reduce handover latency. Soft handover is used to maintain a seamless handover between segments.

In (Shiao-Li Tsao 2002), a gateway approach to macro mobility management between WLAN and UMTS is presented. In this architecture a new logical node connects the two networks together. For inter-working services control and data packets are routed through the gateway. The two networks operate independently and Mobile IP is not necessary. An emulator approach is also presented where the WLAN is used as an access point in the UMTS network. In this sense the WLAN access point emulates a UMTS base station (node-B) or UMTS RNC (Radio Network Controller / packet switching entity in UMTS network).

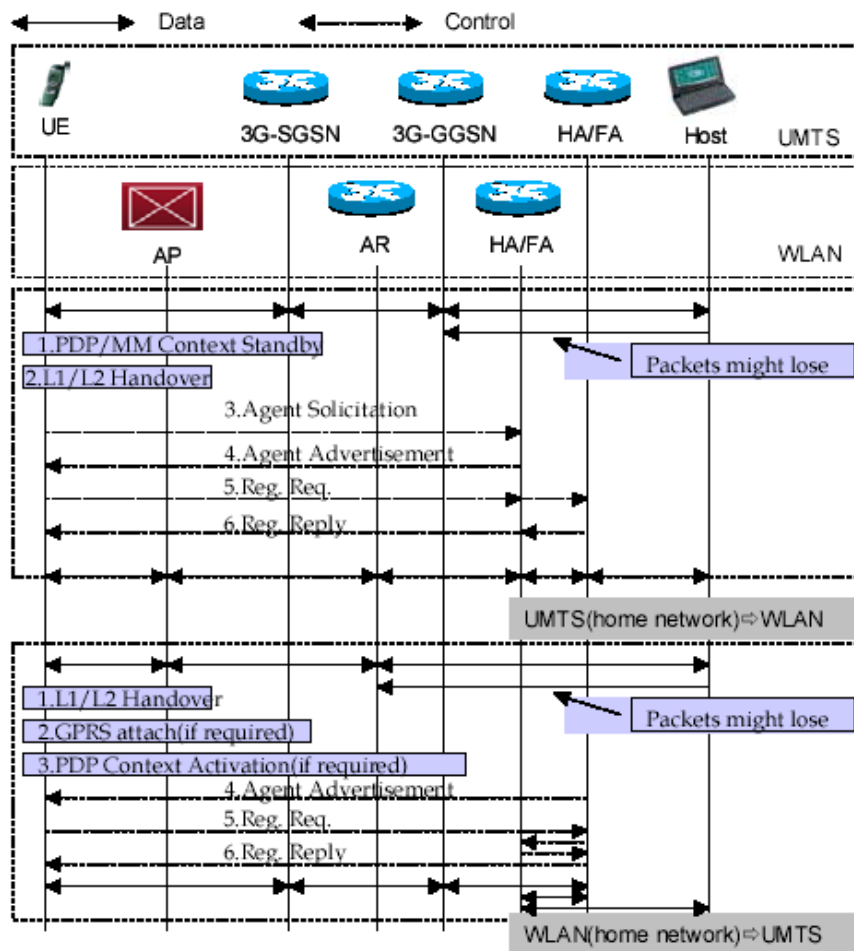


Figure 2. UMTS/WLAN Handover using Mobile IP (S. Li Tsao 2002)

### 3.3.2 Micro Mobility

Movement between points of attachment within a network is known as micro mobility. Fast handover is critical for micro mobility as the handoff rate is very much higher than that with macro mobility and large-scale packet loss and latency are unacceptable.

In (A. Misra 2002), the Intra Domain Mobility Management Protocol (IDMP) is introduced. In the IDMP fast handoff scheme, a mobility agent is situated between the core network and the subnet agents. Before a mobile moves to a new subnet agent, it sends a move imminent message to the mobility agent. The mobility agent then broadcasts all subsequent packets to each subnet agent where they are buffered. When the mobile arrives at the new subnet agent the buffered packets are delivered to the mobile. This can happen before the registration update thus reducing the handover latency and lost packets during handover.

Cellular IP is presented in (Andras G. Valko 1999) as an approach to reduce handover latency and improve the location management for roaming mobile terminals. Cellular IP maintains distributed cache for location management and routing purposes. Distributed paging cache coarsely maintains the position of 'idle' mobile hosts in a service area. Cellular IP uses this paging cache to quickly and efficiently pinpoint idle mobile hosts that wish to engage in active communications. This approach is

beneficial because it can accommodate a large number of users attached to the network without overloading the location management system. Distributed routing cache maintains the position of active mobile hosts in the service area and dynamically refreshes the routing state in response to the handoff of active mobile hosts. The authors argue that by separating local and wide area mobility, the performance of existing mobile host protocols (e.g. Mobile IP) can be significantly improved.

An intelligent handover scheme is presented in (Jon Chiung Shien Wu 2001). The architecture builds on the Mobile IP concept by enabling interaction between layer 2 and layer 3 during the handover process. The solution consists of three extensions.

### **Packet Buffering**

In this scheme, the old FA buffers received packets for a mobile host when it hands over to a new FA. When the handover is complete the old FA forwards the packets to the new FA, thereby reducing the lost packet rate.

### **Neighbour List Update message**

Here the mobile host has access to a neighbour list of candidates the mobile host can roam into from its current location. This enables quicker handoff to a neighbouring network and quicker registration at layer 3.

### **Layer 2-handoff notification to layer 3**

This extension enables layer 3 to know about a handover occurring at layer 2 and doesn't have to rely on timer expiration.

A hierarchy of mobility agents is presented in (Chen Lin Tan 1999) based on the Mobile IP concept to restrict the handoff processing overheads within the vicinity of the mobile node, and uses multicast as the packet forwarding mechanism to deliver packets to multiple base stations within the vicinity of the mobile node to achieve fast handoff performance. Mobiles roaming within a network register their new point of attachment with a DFA (Domain Foreign Agent) within the network. This DFA maintains the bindings for each mobile node within the network. It is only when the mobile moves to a new network (inter network mobility), the home agent has to be informed. To reduce the packet loss when moving between access points, each candidate access point receives the packets for the mobile node and begins to buffer them. When the mobile completes the handover, the packets can be sent from the buffer to the mobile. The buffers in the other access points are then cleared.

### **3.3.3 Admission Control**

Much research has been done on admission control schemes in homogeneous networks with overlaid micro/macro cell structures and interference limited cellular networks such as WCDMA UMTS. Admission control schemes across heterogeneous networks based on radio channel characteristics, resource availability, QoS constraints and user policy still remains an open issue. This section will therefore focus on admission control schemes proposed for a single network, which may be incorporated into an admission control algorithm for heterogeneous networks.

An admission control policy (ACP) for a two tier cellular system with multiple types of service requests is presented in (F. Santucci, 2000). Each service request has different bandwidth requirements and priority. Two types of ACP are investigated – non prioritised and prioritised ACP. In the non-prioritised ACP scheme, all types of calls are treated equally, the scheme is based on a first come first served rule. A call is denied access only if no channel is available. In the prioritised ACP scheme, the policy is based on dropping lower bandwidth calls to serve handover or new call requests of a larger

bandwidth class, thus higher bandwidth calls have a higher priority. This prioritising policy could be useful in a heterogeneous environment where connections with a low bandwidth requirement can be reallocated to a network optimised for that particular data rate and service provisioning and thus leave high speed connections free for users requiring high QoS.

Much literature has been dedicated to Signal to Interference ratio (SIR) based call admission control algorithms for CDMA cellular systems. In (Zhao Liu, 1994), the concept of residual capacity is introduced as the additional number of calls a base station can accept such that the system wide outage probability will be guaranteed to remain below a certain level. The residual capacity is dynamically updated at each cell according to the reverse link SIR measurements at each base station. The residual capacity at each base station is defined as

$$R_k = \begin{cases} \min R_k^{(j)} & \text{if } \min R_k^{(j)} > 0 \\ 0 & \text{otherwise} \end{cases}$$

where  $R_k^{(j)}$  is given by

$$R_k^{(j)} = \begin{cases} \left\lfloor \frac{1}{SIR_{th}} - \frac{1}{SIR_k} \right\rfloor & \text{for } j = k \\ \left\lfloor \frac{1}{\beta} \left( \frac{1}{SIR_{th}} - \frac{1}{SIR_j} \right) \right\rfloor & \text{for } j \neq k \end{cases}$$

$SIR_{th}$  and  $SIR_k$  are the SIR threshold at the BS input receiver and the reverse link SIR for BS k respectively.  $\beta$  denotes the estimate of the interference coupling between adjacent cells. For each call request at cell k, the BS checks the value of the residual capacity,  $R_k$ , if  $R_k > 0$ , the new call is accepted.

It is envisaged that this SIR based admission control policy could be part of the initial stage of network access in a UMTS network. Other parameters such as required QoS, user preference, other current connections etc. will have to be included in the network access decision process.

A much different approach to admission control in WCDMA using neural networks and fuzzy logic is presented in (Chung-Ju Chang, 2000). An intelligent call admission controller adopts fuzzy and neural network techniques to make admission decision for a new call request by considering the QoS measures of all service types, predicted next step call interference and estimated new call interference. The fuzzy interference estimator estimates the equivalent interference, C of a new call from its claimed traffic parameters: peak rate  $R_p$ , mean rate  $R_m$ , peak rate duration  $T_p$  and its outage probability requirement  $P_{otg}$ . A set of fuzzy rules is used to obtain the interference estimate based on the new call parameters. A pipeline recurrent neural network (PRNN) is used for interference prediction. The PRNN takes the mean interference at the present time instant n,  $\bar{I}_k(n)$ , as an input variable to predict the interference mean at the next time instant (n+1),  $\bar{I}_k(n+1)$ . A fuzzy call admission processor takes  $\bar{I}_k(n+1)$ , C and the system outage probabilities of voice and data services denoted  $P_{otg1}(n)$  and  $P_{otg2}(n)$  as input variables to determine the acceptance of a new call request. The smaller the value of C,  $\bar{I}_k(n+1)$ ,  $P_{otg1}(n)$  and  $P_{otg2}(n)$  the higher is the probability that a new call will be accepted.

The call admission control schemes presented herein are designed for a single network. Call admission in a heterogeneous network environment remains an open issue. Such schemes should control the access of users between available networks based on current loads, predicted traffic profiles (Ken Murray, 2001) and the optimality of a network connection to a particular service request.

#### 4. Research Directions

This paper has presented a state of the art survey in mobility management and admission control for heterogeneous wireless networks. Many proposals exist for handover initiation, network selection and handover execution. Admission Control Policies between heterogeneous networks however remains an open issue. Adopting robust and adaptive admission control algorithms will play an important role in the mobility of users through a smart space environment where services can be offered over multiple access networks, which offer varying QoS levels, coverage and capacity.

Future direction will be toward the development of adaptive admission control algorithms for wireless heterogeneous networks. The algorithms must consider user preferences, network load conditions – both current and predicted, the QoS requirement of running applications and the priority of users within the heterogeneous network. The main goal of the algorithm is to create a system that can dynamically adjust the load of users between the available access networks so as to maintain satisfactory QoS levels in a proactive manner. It is envisaged that much of work presented in this paper on handover initiation and network selection can be incorporated into a heterogeneous admission control algorithm.

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