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The Survey of Handoff Issues in Wireless ATM Networks

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Abstract: Wireless ATM (WATM) has emerged as an important component of the broadband wireless network infrastructure. While ATM supports for different traffic characteristics and QOS requirements, WATM networks provide wireless extension to the ATM-based B-ISDN networks by adding mobility support functions. The implementation of WATM poses several problems like mobility management, radio access to network etc. This paper presents the literature survey of WATM and its handoff related issues. The paper reviews ATM fundamentals and its benefits. It deals with WATM features, requirements, protocol architectures and the global activities. The focus is made on the handoff related aspects of WATM: the handoff management operation, requirements, protocols, proposed solutions and open issues for research.

Keywords:ATM; wireless ATM; location management; Handoff; QoS etc

1 Introduction

The ATM is viewed as the next generation high speed integrated network paradigm, supporting different classes of traffic and providing quality of service (QoS). Mobile communications have evolved and created a significant impact on the way of work and communication. The convergence of mobile communications, computing and ATM gave rise to Wireless ATM (WATM) networks. While ATM helps to bring multimedia to the desktop, WATM provides similar services to mobile computers and devices. WATM networks provide seamless integration with ATM-based B-ISDN networks. The WATM can be viewed as a solution for next-generation personal communication networks (PCN), or a wireless extension of the B-ISDN networks, that support integrated data transmission (data, voice, video) with guaranteed QoS requirements. The implementation of wireless ATM presents a number of technical challenges that need to be resolved.

1. The need for the allocation and standardization of appropriate radio frequency bands for broadband communications.
2. Requirements of new radio technology and access methods for high speed operation.
3. Location management for tracking mobile terminals as they move around the network.
4. Handoff management for dynamic reestablishment of virtual circuits to new access points while ensuring sequenced and loss-free delivery of ATM cells.
5. End-to-end QoS provisioning, which is challenging in case of limited bandwidth, time-varying channel characteristics and terminal mobility.

The organization of the paper is as follows. Section 2 reviews ATM fundamentals and its benefits. Section 3 discusses the fundamentals of Wireless ATM: WATM network model, need for WATM, its features, service requirements, protocol architecture, characteristics and the global activities. The Handoff related

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aspects of WATM are covered in section 4, which includes Handoff operations, requirements, protocols, related works and the open issues. Finally, section 5 concludes the discussion.

2 Asynchronous Transfer Mode (ATM)

2.1 Basic Principles of ATM

The Asynchronous Transfer Mode (ATM) is a data transport technology that supports a single high-speed infrastructure for integrated broadband communication involving voice, video and data. The important features of ATM technology include: short fixed-size packets or cells, virtual circuits, statistical multiplexing, and integrated services. All these concepts together provide a uniform framework that can carry multiple classes of traffic provided with a guaranteed QoS.

ATM is a connection-oriented transmission technology in which information is transmitted in the form of small packets called cells. Each ATM cell is a small 53 bytes packet comprising of a 5 bytes header and a 48 bytes data field [1]. The building blocks of ATM networking are the transmission path, the Virtual Path (VP) and the Virtual Channel (VC). A transmission path contains one or more VPs and a VP contains multiple VCs trunked into it.

The ATM Forum has classified QoS classes available to the VP and VC connection options as *Specified QoS* (most stringent and most versatile) and *Unspecified QoS* (less stringent and expensive). For *Specified QoS*, service providers must meet agreed parameters: *Maximum Cell Transfer Delay, Maximum Cell Delay Variation, Maximum Cell Loss Rate* and *Maximum Burst Cell Loss*. For *Unspecified QoS*, no network performance parameters are specified. However, the network provider may determine a set of internal objectives for the performance parameters.

2.2 Benefits of ATM

Broadly speaking, ATM has advantages in three folds (Fig.1): accommodating mixed media traffic, simplified network infrastructure, scalability and flexibility in bandwidth and network sizes.The benefits of ATM include:

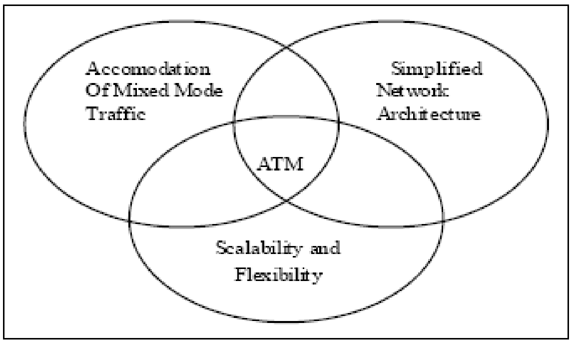

Figure 1: Advantages of ATM.

- High Performance via Hardware switching.
- Dynamic bandwidth for bursty traffic.
- Class of service support for multimedia.
- Scalability in speed and network size.
- Common architecture for LAN, MAN and WAN.
- Opportunity for simplification via Virtual Circuit (VC) architecture.
- International standard compliance.

3 Wireless ATM

3.1 WATM Network Model

Wireless ATM is an emerging network technology that combines the multi-service, multimedia capabilities of ATM with user mobility and wireless access. The need for the Wireless ATM arose due to the sophistication of end-user telecommunications services and applications, the development of portable, multimedia capable end-user platforms and the benefits of the ATM.

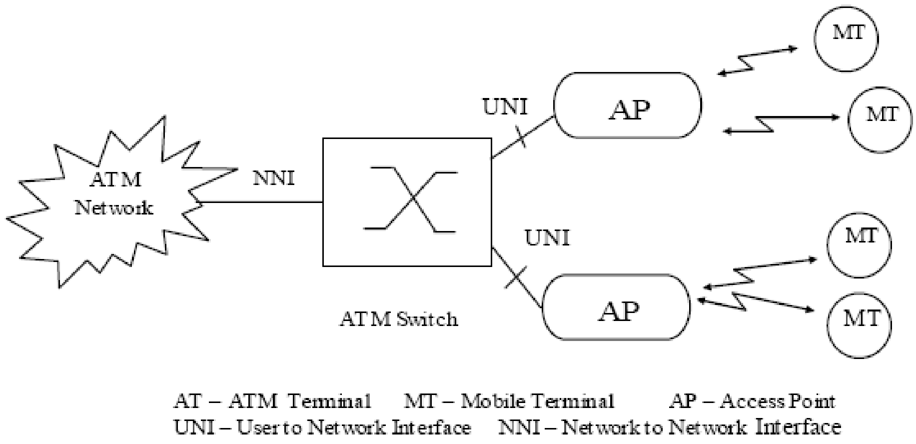

Figure 2: WATM Network Architecture.

The WATM concept extends ATM into the wireless environment, by adding mobility and radio aspects into the ATM transmission. The concept of wireless ATM was explained earlier in [4, 9]. Fig.2 shows the WATM network architecture. It comprises of Mobile Terminals (MT), Access Points (AP) and ATM switches. Some of the distinguishing features of wireless ATM are listed below [7].

- It supports wireless access to telecommunication services with a high multimedia content, including interactive voice, video and packet data.
- It provides at least limited terminal mobility, i.e. the capability of a user to maintain communication through a fixed infrastructure while moving the wireless ATM terminal device between access point.
- It is deployed well integrated into the ATM infrastructure used for fixed communication, such that it will not affect fixed-only communication.
- It is implemented in a way that allows sharing of key network resources, such as transmission links and switches.

3.2 WATM Service requirements

The Wireless ATM aims at supporting various types of services like text, data, audio, video and multimedia applications. The services may be connection-oriented (CO) or connectionless (CL). They include constant bit rate (CBR), variable bit-rate (VBR) and available bit rate (ABR), that provides *best effort* service. WATM should support a reasonable range of service classes, bit-rates and QoS levels associated with ATM [5]. Table.1 summarizes typical targets for WATM service capabilities.

3.3 WATM Protocol Architecture

The WATM protocol architecture is based on integration of radio access and mobility features within the standard ATM protocol stack (Fig. 3, 4). It facilitates for gradual evolution of radio access technologies without modifying the core mobile ATM network specifications [10]. While [2, 8] deals with the architectural design aspects of WATM, [3, 6] highlights the limits, challenges of WATM and the proposals.

A WATM system broadly consists of a *Radio Access Layer* and *Mobile ATM* network.

Table 1: Wireless ATM requirements

Traffic Class	Application	Bit-rate range	QoS Requirement
CBR	Voice and Digital TV	32 Kbps- 2 Mbps	Isochronous Low Cell Loss Low Delay Jitter
VBR	Video Conferencing Multimedia communication	32 Kbps- 2Mbps (avg) 128 Kbps-6 Mbps (max)	Moderate Cell Loss Low Delay Jitter Statistical Mux.
ABR	Interactive data Client-server	1- 10 Mbps	Low Cell Loss Can tolerate higher delays High burst rate

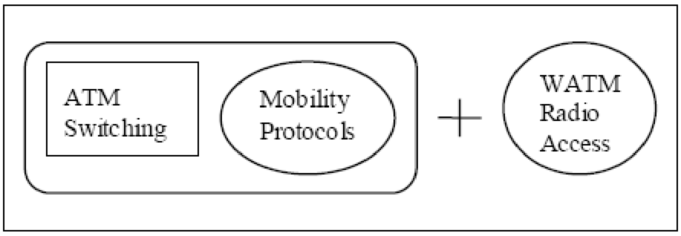

Figure 3: Modular Protocol Architecture of WATM System..

1. Radio Access Layer (RAL) is responsible for the radio link protocols for wireless ATM access. Radio Access Layers consists of PHY (Physical Layer), MAC (Media Access Layer), DLC (Data Link Layer) and RRC (Radio Resource Control). The RAL requirement details are explained in [13].

2. Mobile ATM deals with control/signaling functions needed to support mobility. These include *location management*, *handover* and *connection control*. Location management is responsible for keeping track of the MT. Handover (or Handoff) refers to the process of rerouting the mobile terminal connections from the old to the new base station. Connection control deals with connection routing and QoS maintenance.

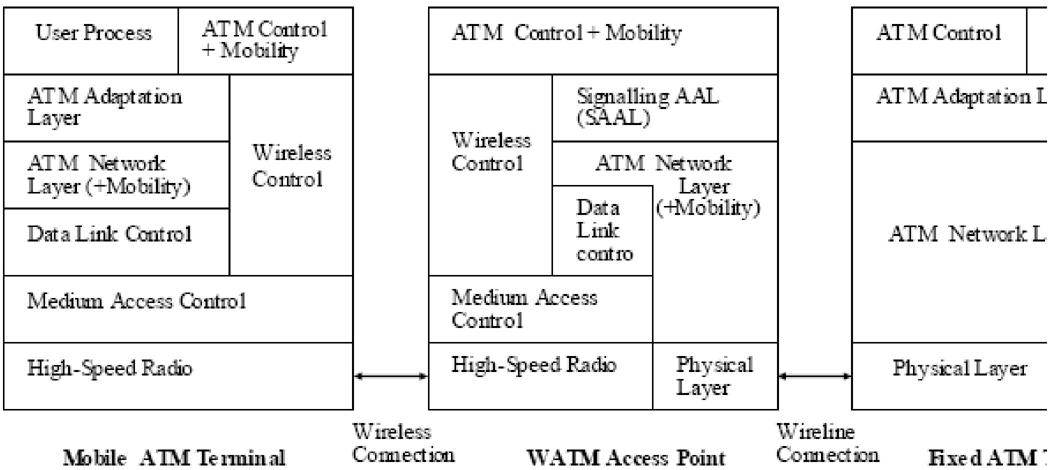

Figure 4: Wireless ATM Protocol Stack Architecture.

3.4 WATM Characteristics

The Key aspects of WATM and mobility extensions, added to the fixed ATM network are explained as follows [14].

1. *Cellular Architecture*: In WATM, the geographical area is organized into small cells. The cellular organization of space potentially poses problems like increased handoff rates (due to crossings across the cells). The sharing of bandwidth and re-using of frequencies gives rise to the problem of co-channel interference. Lesser the cell size accommodates greater capacity per unit area, but it increases handover rate and in turn dropping rate due to increased crossings across the cells.

2. *Resource Allocation*: QoS provisioning is an important consideration in WATM networks. An explicit resource allocation using a combination of admission, traffic shaping and policing mechanisms is used to achieve it. The connection admission mechanism must take into account possible congestion, also ensure a low rate of dropped connections as users roam among different wireless coverage areas. The admission control is based on several criteria such as: traffic and handover characteristics, call holding time statistics, desired QoS of each class of traffic and amount of radio resource available.

3. *Mobility Management*: Mobility management [15-22] deals with issues such as handover signaling, location management, and connection control. *Location management* [48-52] is responsible for locating the mobile node. It involves two-stage process: *Location Registration* and *Call Delivery*. In the first stage, the MT periodically notifies the network of its current location and allows the network to update its location profile. The second stage involves querying the network for the user location profile in order to route incoming calls to the current location of MT. Two basic location management schemes have been proposed in [48]: the *Mobile PNNI scheme* and the *Location register scheme*. The *Handoff Management* [14, 45-47] is responsible for rerouting the mobile terminal connections from the old to the new base station. *Connection control* deals with connection routing and QoS maintenance.

3.5 Global activities on Wireless ATM

WATM technology is migrating from research stage to standardization, lead by the ATM Forum ETSI since 1996. The charter has been developed saying [12]: *"The Wireless ATM (WATM) Working Group will develop a set of specifications intended to facilitate the use of ATM technology for a broad range of wireless network access scenarios, both private and public. These specifications will include both "mobile ATM" extensions for mobility support within an ATM network, as well as "radio access layer" for ATM-based wireless access, and will be designed for compatibility with ATM equipment adhering to the (then) current ATM Forum specifications. Explicit liaison arrangements will be established with relevant standards bodies"*.

The WATM Working Group of the ATM Forum produced its first draft specification in December 1998 [11]. The following is the list of several projects focusing on or related to WATM carried out in various organizations [7, 8].

1. *Magic WAND* (Wireless ATM Network Demonstrator): Magic WAND is a joint European project intended to develop demonstration MTs for multimedia information access using a fast and wireless ATM network. It uses 5 GHz band for communications between MT and the ATM switches.

2. *MEDIAN* (Wireless Broadband CPN/LAN for Professional and Residential Multimedia Applications): The main objective of MEDIAN is to evaluate and implement a high speed wireless customer premises local area network pilot system for multimedia applications. It support wireless ATM network extension. It uses 60 GHz band to provide bit rates up 155 Mbps.

3. *AWACS* (ATM Wireless Access Communication System): AWACS's main objective is to develop a system concept and test bed demonstration of wireless public access to B-ISDN services. It uses 19 GHz band to provide bit rates up to 34 Mbps.

4. *ORL Radio ATM*: ORL (The Olivetti and Oracle Research Laboratory) has designed wireless ATM system as an extension to existing ATM LANs. The system is based on pico-cells. Each cell has a base station. The MTs communicate with each other via base stations which forms an ATM network.

5. *RDRN* (Rapidly Deployable Radio Networks): The RDRN is a high-speed ATM-based wireless network architecture and protocols designed to be adaptive at both the link and network levels to allow for rapid deployment and automatic reconfiguration in a changing environment.

6. *SWAN*, Bell Laboratories: It is the first wireless ATM systems that supported full ATM connectivity and mobility based on handovers between access points. It uses a 1 Mbps radio subsystem.

4 Handoff in Wireless ATM Networks

4.1 Handoff Management operation

The Handoff management enables a Mobile Terminal (MT) to move seamlessly from one access point (AP) to another, while maintaining the negotiated Quality of Service (QoS) of its active connections. Handoff Management involves three-stage process as in Fig.5. [16]:

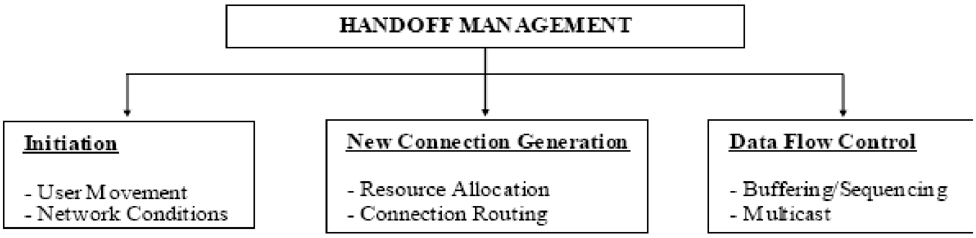

Figure 5: Handoff Management Operations.

1. Initiation: It involves handoff decision making, wherein the need for handoff is identified by either MT or network agent. Various handoff initiation criteria, kinds of handoff decision are discussed in [46]. [23, 24] describes the optimum selection of handoff initiation algorithm and related parameters.

2. New Connection generation: It involves the generation of new connections which comprises of finding new resources and performing additional routing operations.

3. Data flow control: It involves data delivery along new established path with the agreed QoS guarantees.

4.2 Handoff Types

Wireless ATM supports the following handoff types. The handoff type used in a system depends on the radio interface technology used [35, 38].

1. *Backward Handoff*: In backward handoff, the handoff is predicted in advance using radio hint and the execution of handover is initiated via current access point.

2. *Forward handoff*: In forward handoff, a MT moves abruptly to new access point and handover is initiated after the mobile is associated with new access point.

3. *Hard Handoff*: In hard handoff, MT communicates with only one access point at any time. They are characterized by *break before make*. The current resources are released before new resources are used.

4. *Soft Handoff*: In soft handoff, a mobile can communicate with more than one access points during handoff. They are characterized by *make before break*. Both current and new resources are used during handover.

4.3 Handoff Requirements

The requirements for the handoff procedure are listed in ATM Forum/96-989 [25, 26].

1. *Handoff Latency*: The delays and delay variations during handoffs should be minimized to guarantee the QoS of WATM connections.

2. *Scalability*: The handoff procedure should support seamless handoff between APs in different private and/or public networks.

3. *Quality of Service (QoS)*: QoS guarantees negotiated with connections should be preserved during handover. The important traffic parameters to be considered are Cell Loss Ratio (CLR) and Cell Delay Variation (CDV).

4. *Signalling Traffic*: Handoff signaling traffic should be kept to a minimum in order to reduce the load on the wired network and the air interface to the MT.

5. *Resource consumption efficiency*: Handoff procedure should aim at low buffer consumption to reduce latency and minimize the consumption of bandwidth.

6. *Data Integrity* : It includes minimization of cell loss, avoiding of cell duplication and maintaining cell-sequence for each connections.

7. *Group Handover*: The efficient handoff of multiple active VCs should be supported by the Handoff procedure.

8. *Registration and Authentication*: The handoff of the MT should not compromise the established security between the MT and network.

4.4 Handoff Protocols

The Proposed handoff protocols can be classified into four categories [16]:

1. *Full Connection Re-routing*: It involves the establishment of a new VC as if it is a new call. An Inter-Working Devices Handoff scheme proposed in [30] makes use of external processors called Inter-Working Devices (IWDs) to manage handoff. These techniques are optimal, but latent due to the need of computation of new routes.

2. *Route Augmentation*: It involves route extension by adding a route from last position to current position of MT. It offers a simplest means of achieving handoff, since it requires no cell sequencing, little buffering and not much additional routing. It does not provide optimal path.

3. *Partial Connection Re-routing (Incremental Re-establishment)*: In this technique, a part of route is preserved for simplicity, while the rest is re-routed for optimality. The Nearest Common Node Rerouting (NCNR) algorithm presented in [28], routes the connection according to the residing zone of MT. The NCNR attempts to perform the rerouting for a handoff at the closest ATM network node that is common to both zones involved in the handoff transaction. The Hybrid Connection algorithm presented in [31] consists of Cross-Over Switch (COS) discovery. In case of intra-cluster handoff, the cluster switch itself performs the handoff at COS. In inter-cluster handoff, the COS discovery process is initiated, based on the handoff hint message provided by the MT. A partial path is setup between the COS and target switch, while the rest of the old path is preserved. This technique provides better resource utilization and reduced signaling, but requires computation of nearest node or COS, buffering and cell sequencing.

4. *Multicast Connection Rerouting*: This method combines the above three techniques. It pre-allocates resources in the network portion surrounding the macro-cell where the mobile user is located. When a new mobile connection is established, a *virtual connection tree (VCT)* [27] is created, connecting all Base Stations (BSs) including the macro-cells towards which the MT might move in the future. Thus, the mobile user can freely roam in the area covered by the tree without invoking the network call acceptance capabilities during handover. The allocation of the VCT may be static or dynamic during the connection tenure. This approach is fast and can guarantees the negotiated QoS in case of network handover, but it may not be efficient in terms of network bandwidth utilization, since there exists the possible denial of a connection due to lack of resources and high signaling overheads, especially in the case of dynamic tree allocation.

A summary of comparison of handoff management approaches is listed in table 2 [16]. The detailed analysis can be found in [29].

Table 2: Comparison of handoff management approaches.

	Full	Extension	Partial	Multicast
Merits	-Optimal Route -Existing Methodology	-Fast -Maintains cell sequence	-Maintains cell sequence -Reduced resource utilizations	-Fast -Maintains cell sequence
Demerits	-slow -Inefficient Resource Reassignments	-Wastes Bandwidth -Inefficient routing of connections	-Complex -Needs added switching	-Needs extra Buffer -Bandwidth Pre-allocation

4.5 Related works on Handoff Solutions

This section presents several proposed handoff algorithms that cater various requirements of the WATM. Toh [32] proposed a handover scheme that exploits the radio hint and employs the partial path setup. This scheme assumes that MT can at any time access only one new AP and handover is initiated by MT.

Yuan et al.[33] proposed a generic AP-initiated, inter-switch handover procedure in which the current AP uses the wireless control protocol to contact the neighboring APs that serve as handover candidates. In this case, the AP instead of the switch determines the next possible AP to be used by MT. From the network perspective, AP-controlled handovers may not yield optimal results with respect to the resource consumption requirements.

J. Naylon [34] proposed a handover protocol that offers low-latency Handoff. The proposed protocol uses a two-phase backward handover that decouples the re-routing of MT connections from the radio handover and minimizes the interruption to data transport. The introduction of user-plane connections for the low-latency transport of handover messages between the mobility-supporting software entities enables reduction of the latency.

H. Mitts et al. [35] presented a lossless approach for intra-switch handovers. The design aims at a lossless handover that also has low delay and delay variations. The buffering requirement at APs is also modest. It supports both forward and backward handoffs.

Li, Acharya [36] proposed the zero-cell-loss handoff in WATM networks. The proposed protocol makes use of in-band signalling along with a cell-level scheduler supported by ATM Hardware (switches, NIC cards etc.). It integrates the in-band signaling and ATM UNI or NNI out-band signalling in appropriate sequence to reduce the possible cell loss.

A two-phase handoff protocol proposed by Wong [40] and Salah [41] combines the connection extension and partial re-establishment schemes. The two-phase handoff protocol consists of two phases- path extension and path optimization. Path extension is performed for each inter-switch handoff. Path optimization is activated when the delay constraint or other cost is violated.

In [39], a combined QoS-based path optimization scheme is proposed that activates the path optimization, when the delay and path extension hops exceed the maximum value. The results depict that the QoS based path optimization scheme outperforms the delay-based and hop-based optimization schemes in terms of handoff-drop rates, average number of hops and average link delay.

In [42], two handover algorithms are proposed, which aims at improving two parameters of QoS: blocking calls and dropping handovers. The first algorithm, Uniform Pre-establishment Algorithm (UPA) pre-establishes paths uniformly in all neighboring clusters surrounding the mobile. The second algorithm, Pre-establishment Algorithm (PAP), pre-establishes paths in the neighboring clusters located on highly probabilistic directions potentially used by mobile.

Akhyol in [53] proposed two signaling architecture alternatives: overlay signalling and migratory signalling. The overlay signalling keeps the existing signaling protocol intact and functions as an overlay network. It aims at minimizing the modification needed to the existing ATM protocols. The migratory signalling approach implements a single signalling protocol for support of both wireless and wired users. The migratory signalling protocol supports upgrading of the network in phases or in regions while maintaining compatibility with the existing network. The migratory signalling approach integrates wireless and wired users into one global wireless ATM network at the cost of requiring some modifications to the existing ATM protocols.

Marsan et al. in [37] presented a method for the dynamic reestablishment of VCs within the short time span of the MT handover from one macro-cell to another. The use of in-band signalling and reserving buffering resources at the destination base station enables VC reestablishment with guaranteed in-sequence and loss-free ATM cell delivery. The in-band signalling approach allows for a progressive upgradation of the fixed part of the ATM network and for the incremental introduction of user terminal mobility.

[43] introduces a three-level multi-agent architecture for QoS control in WATM. It addresses the management of buffer space at the level of a switch using agents and the dynamic reconfiguration of agents during handoff to meet the QoS requirements. [54] presents an analytical modeling approach to estimate the performance of handover protocols making use of handover buffers at the base station.

[55] discusses a class of Geom/Geom/1 Discrete-time Queueing System with negative customers, which can be used for modelling nodes in WATM networks. The negative customers can facilitate modelling server failures, cell losses, channel impairments etc. in WATM networks. The grey complex network [56] helps to resolve system problems with missing information.

4.6 Handoff Management Issues

Handoff management has posed several challenges in the implementation of wireless technologies. The open issues are listed below.

1. QoS: The main issue to be considered is guaranteeing of negotiated QoS. The critical factors influencing QoS disruption during handoff are - handover blocking due to limited resources, cell losses, out-of-order cell delivery, delay and delay variations. Minimization of QoS disruption can cost buffering. The QoS provisioning also needs to address the timing and synchronization issues. [44] discusses local and global adaptive synchronization criteria based on Lyapunov stability theory for the uncertain complex delayed dynamical networks.

2. Rerouting Connections: The issues remain in development of algorithms for finding new route options, creation of signalling protocols for reconfiguring the connection path and determination of the feasibility of proposed solutions.

3. Point to Multipoint: Development of protocols that address rerouting the point-to-multipoint connections of MTs.

4. Mobile-to-Mobile Handoff: Need to address upgradation of existing protocols in order to support connection routing and QoS for a mobile-to-mobile connection.

5. Optimization: Development of efficient methods that allow an existing MT connection to be periodically rerouted along the optimal path.

5 Conclusion

Wireless ATM provides wireless extension to ATM based ISDN networks. This paper reviews the important aspects of wireless ATM and the handoff related issues. It reviews the basic concepts and benefits of ATM. Then the important features of WATM, service models, protocol model, the key characteristics of WATM and the global activities on WATM are dealt. The paper focusses on the survey of Handoff techniques in WATM and related issues. The Handoff requirements, various strategies and open issues are discussed.

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