A Control and Management Network for Wireless ATM Systems

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Abstract

This work provides the results of the on-going design and implementation of a control and management network (an orderwire) for a mobile wireless ATM system. There are novel uses for an orderwire which receives time and position from the Global Positioning System (GPS). Position information is used for such things as beam steering and determination of switch to host associations. The accurate time provided by the GPS is used by the network configuration system for a proposed rapid configuration algorithm.

1: Introduction

This work presents the results of development completed to date on a network configuration system for a Rapidly Deployable Radio Network (RDRN).

The Rapidly Deployable Radio Network is a high capacity rapidly deployable wireless ATM network comprised of switch and host nodes.

Research involving mobile ATM has only recently begun; therefore, literature in this area is scarce. Discussion of a wireless protocol stack is given in [10]. A tree based method for low overhead handoff with ATM is explained in [1]. An interesting mobile LAN ATM architecture is provided in [5]. Finally, [3] provides an analysis of switch buffer fill distribution in a mobile ATM environment.

The RDRN architecture is composed of three overlaid networks:

- a low bandwidth, low power omni-directional network for location determination, switch coordination and management (the orderwire network),
- a "cellular like" system for multiple end-user access to the switch using directional antennas, and
- a high capacity, highly directional, multiple beam network for switch-to-switch communication.

The network currently consists of two types of nodes, edge nodes (EN) and remote nodes (RN). Edge nodes reside on the edge of a wired network and provide access to the wireless network. The Edge Node components include the ATM switch, high speed radio, AX.25 packet radio for the low speed orderwire, GPS receiver, and an additional processor for the network configuration system. Host nodes or remote nodes (RN) consist of the above, but do not contain an ATM switch. The ENs and RNs also include a phased array steerable antenna. The RDRN uses position information from the GPS for steering antenna beams toward nearby nodes and nulls toward interferers, thus establishing the high capacity links.

The orderwire network uses a low power, omnidirectional channel, operating at 19200 bps, for signaling and communicating node locations to other network elements. The orderwire aids link establishment between the edge nodes and between the remote and edge nodes, tracking remote nodes and determining link quality. The orderwire operates over the packet radios and is part of a larger network configuration system. An example of the high speed and orderwire network topology is shown in Figure 1. In this figure, an EN serves as a link between a wired and wireless network, while the remaining ENs act as wireless switches. The protocol stack for the high speed network is shown in Figure 2.

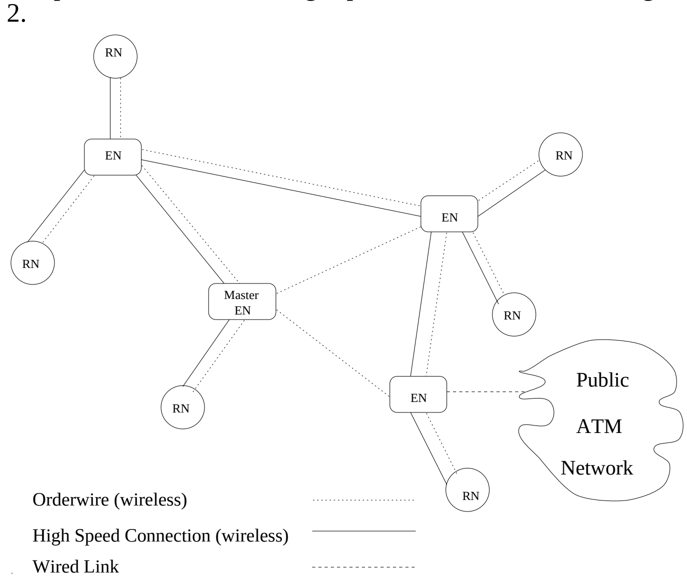

Figure 1. Example Orderwire Topology.

The focus of this paper is on the network configuration system and in particular on the orderwire. This includes protocol layer configuration, link quality, handoff, and host/switch assignment along with information provided by the GPS system such as position and time. The details of the high speed network will be covered in this paper only in terms of services required from, and interactions with, the network configuration system.

We will now provide a brief overview of the high speed protocol architecture for this wireless ATM network with the aim of identifying the requirements that each layer will have for the network configuration system. The physical layer includes all the hardware components such as the high speed radios, ATM

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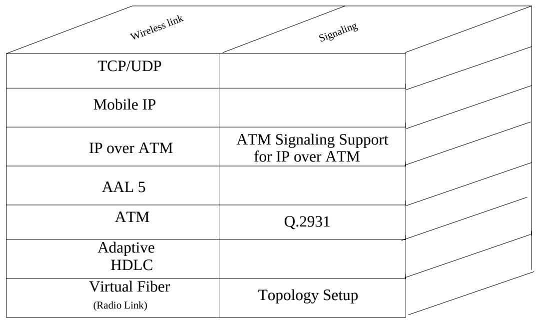

Figure 2. High Speed Protocol Stack.

switch, antennas, and additional processor for configuration and setup (orderwire) as well as the wireless connections. At this layer, the network configuration system is designed to determine an association of RNs to ENs which will provide a given QoS, and to establish the wireless (virtual fiber) connections. The data link layer will be adaptive to provide an appropriate degree of data rate versus reliability in order to properly support the various types of ATM traffic and will carry ATM end-to-end. In a PVC environment, the ATM layer network configuration system will automatically setup fully meshed PVC among all remote nodes, while in an SVC environment, the network configuration system will establish the switching VC between the host and switch. The Mobile IP layer, whose main function is to provide routing between subnetworks and service for TCP and UDP transport layers, requires information such as a RN's home agent and foreign agent for an Logical IP Subnet (LIS). The information required by the ATM, IP and TCP layers will be exchanged over the orderwire through special packet types.

The next section describes the network configuration protocol layers, packet types, and operation while Section 3: describes a virtual time mechanism for rapid network reconfiguration.

2: Network Configuration System Overview

This section describes an initial implementation of the RDRN network configuration system for the prototype system currently under construction, [2]. Each layer of the high speed radio connection will have a corresponding layer in the network configuration system, as shown in Table 1.

The following is a description and ordering of events for the establishment of the wireless connections.

Protocol Layer	**Packet Types**
ATM	VC_SETUP
Radio Setup	USER_POS NEWSWITCH HANDOFF MYCALL SWITCHPOS TOPOLOGY

Table 1. Network Configuration System Layers.

MYCALL
Callsign
Start-Up-Time

Table 2. MYCALL Packet Contents.

2.1: Physical Layer

At the physical level we will be using the orderwire to exchange position and link quality information and to setup the wireless connections. The process of setting up the wireless connections involves setting up links between edge nodes and between edge and remote nodes.

The network will have one master switch (EN), which will run the topology configuration algorithm [6] and distribute the resulting topology information to all the connected ENs over point-to-point packet radio links. The point-to-point link layer is AX.25 [7].

The master EN could initially be the first active EN, and any EN would have the capability of playing the role of the master.

The first EN to become active would initially broadcast its callsign(where callsign = radio address) and start-up-time in a **MYCALL** packet (Table 2), and listen for responses from any other ENs. Since it is the first active EN, there would be no responses in a given time period, say T. At the end of T time, the EN could rebroadcast its **MYCALL** packet and wait another T seconds. At the end of 2T seconds, if there are still no responses from other ENs, the EN assumes that it is the first EN active and takes on the role of the master. If the first two or more ENs start up within T seconds of each other, at the end of the interval T, the EN could compare the start-up times in all the received **MYCALL** packets and the EN with the oldest start-up time would become the master.

Each successive EN that becomes active would initially broadcast its callsign in a **MYCALL** packet. The master on receipt of a **MYCALL** packet would extract the callsign of the source of the packet, establish a point-to-point link to the new EN and send it a **NEWSWITCH** packet (Table 3). The new EN on receipt of the **NEWSWITCH** packet over a point-to-point link, would obtain its position from its GPS receiver and send its position to the master as a **SWITCHPOS** packet (Table 4) over the point-to-point link. On receipt of a **SWITCHPOS** packet, the master would record the position of the new EN in its "switch position" table (table of EN positions), and run the topology configuration algorithm [6], to determine the best possible interconnection of all the ENs. The master would then distribute the resulting information to all the ENs in the form of a **TOPOLOGY** packet (Table 5) over the point-to-point links. The EN can then use this information to setup the high-speed links as specified by the topology algorithm. The master would also distribute a copy of its "switch position" table to all the ENs (over the point-to-point links), which they can use in configuring RNs as discussed below. This sequence of operations is illustrated in Figure 3 and Figure 4. Also, the EN can then use the callsign information in the "switch position" table to setup any additional point-to-point packet radio links (corresponding to the high-speed links) required to exchange any link quality information. Thus this scheme would result in point-to-point packet radio links from the master to every EN (a point-to-point star network with the master as the center of the star) and also between those ENs that have a corresponding high-speed link, as shown in Figure 1.

In the event of failure of the master node (which can be detected by listening for the AX-25 messages generated on node failure), the remaining ENs exchange **MYCALL** packets, elect a new master node, and the network of ENs is reconfigured using the topology configuration algorithm [6]. The efficiency of this method of handling failure of the master node versus maintaining a hot backup for the master node is to be studied.

Each RN that becomes active would obtain its position from its GPS receiver and broadcast its position as a **USER_POS** packet (Table 6). This packet would be received by all the "nearby" ENs. Each candidate EN would then compute the distance between the RN and all the candidate ENs (which is possible since each EN has the positions of all the other ENs from the "switch position" table). An initial guess at the best EN to handle the RN would be the closest EN. This EN would then feed

NEWSWITCH

Table 3. NEWSWITCH Packet Contents.

SWITCHPOS
GPS time
GPS position

Table 4. SWITCHPOS Packet Contents.

TOPOLOGY
Number of Elements
Array of Callsigns and Positions of each element

Table 5. TOPOLOGY Packet Contents.

USER_POS
Callsign
GPS time
GPS position

Table 6. USER_POS Packet Contents.

HANDOFF
Time Slot
Frequency
Phase

Table 7. HANDOFF Packet Contents.

VC_SETUP
IP Address
VCI

Table 8. VC_SETUP Packet Contents.

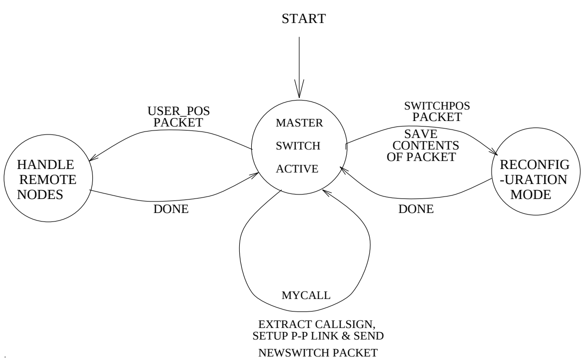

Figure 3. State Diagram for Master.

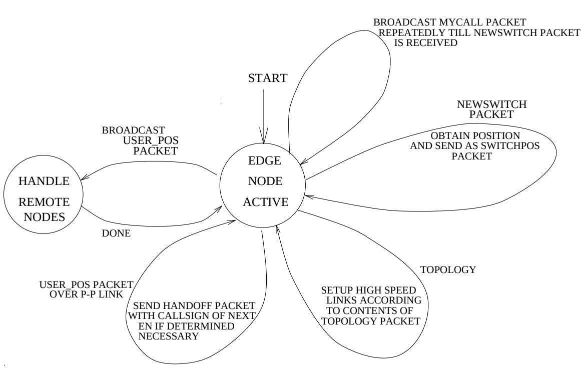

Figure 4. State Diagram for EN not serving as Master.

the new RN's position information along with the positions of all its other connected RNs to a beamsteering algorithm that returns the steering angles for each of the beams on the EN so that all the RNs could be configured. If a time slot and/or beam is available to fit in the new RN (this information will be returned by the beamforming algorithm), the EN would steer its beams so that all its connected RNs and the new RN are configured, record the new RN's position in its “user position” table (table of positions of connected users), establish a point-to-point link to the new RN and send it a **HANDOFF** packet (Table 7) with link setup information indicating that the RN is connected to it. If the new RN cannot be accommodated, the EN would send it a **HANDOFF** packet with the callsign of the next closest EN, to which the RN could send another **USER_POS** packet over a point-to-point link. This EN could then use the beamform algorithm to determine if it could handle the RN, and so on. Figure 5 shows the states of operation and transitions between the states for a RN.

This scheme thus uses feedback from the beamforming algorithm together with the distance information to configure the RN. It should be noted that the underlying AX.25 protocol [7] ensures error free transmissions over point-to-point links. Also the point-to-point link can be established from either end and the handshake mechanism for setting up such a link is handled by AX.25. If the RN does not receive a **HANDOFF** packet within a given time it can use a retry mechanism to ensure successful broadcast of its **USER_POS** packet.

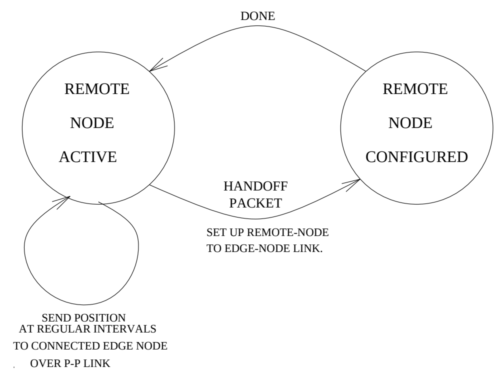

Figure 5. State Diagram for RN.

The point-to-point orderwire links would be retained as long as a RN is connected to a particular EN and a corresponding high-speed link exists between them (to enable exchange of link quality information). The link can be torn down when the mobile RN migrates to another EN in case of a handoff.

2.2: Bandwidth required for the Orderwire Network

The traffic over the orderwire was analyzed to determine a relation between the maximum update rate and the number of RNs. The protocol used for contention resolution on the broadcast channel is the Aloha Protocol which is known to have a maximum efficiency close to 18%. Given the bandwidth of the orderwire channel, size of an orderwire packet and this value for the efficiency, we compute and plot the value for the maximum update rate (in packets per minute) for a given number of RNs. The plot of Figure 6 shows the variation in update rate for between 20 and 80 RNs. Thus this study gives us an upper limit on the number of RNs that can be supported over the orderwire given a minimum required update rate.

2.3: Establishing an End-to-End Connection

The following sections describe the operation of the network configuration system in establishing ATM connections.

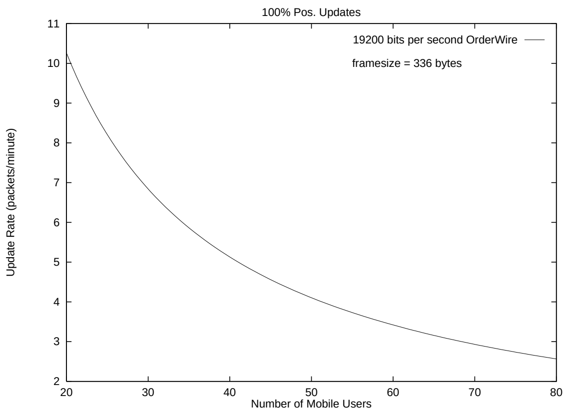

Figure 6. Traffic Analysis.

2.3.1: ATM Network Configuration Layer

This section describes virtual circuit setup by the network configuration system. There are two approaches at this level, depending on whether switched virtual circuits (SVCs) or Permanent Virtual Circuits (PVCs) are available. RFC1577 [8] is followed on both the fixed and wireless networks. A Logical IP Subnet (LIS) can be comprised of fixed and wireless portions of the network.

When PVCs are used, the network configuration system establishes a fully meshed VC connections as follows. The EN on receipt of a **USER_POS** packet (Table 6) from a new physically connected RN sends pairs of **VC_SETUP** packets (Table 8) to the new RN and each one of the existing RNs. Each **VC_SETUP** packet contains a designated IP address of the new RN and a VCI number identifying the VC to be setup. The RN on receipt of each pair of **VC_SETUP** packets, extracts the IP address and VCI number from each **VC_SETUP** packet and uses it to setup the VC. Since the **VC_SETUP** packets are sent in pairs to the new RN and to each of the existing RNs for each RN in the network, VCs will be setup between the new RN and each of the existing RNs resulting in a fully meshed VC configuration as desired.

If switched virtual circuits are used, only the signaling VCs as specified in the standards will be established in a manner similar to that described above.

2.4: Timing Results

This section summarizes the results of some timing experiments that were undertaken to examine the performance of the orderwire system. The experiments involved determining the time required to transmit and process each of the packet types listed in Table 1 using the packet radios. Only two packet radios were available for development and experimentation, and three packet radios are required for the simplest RN to RN connection through an EN. Thus the timing for the DEC AN2 switch VC setup and handoff emulation was carried out using TCP/IP to emulate packet radios while using the actual network configuration software. Figure 7 illustrates the physical setup used for these experiments while Figure 8 illustrates the physical setup used for the experiments involving the real packet radios. The results are presented in Table 9. Since the workstations being used for our experiments were also being used by other users, the measured times are probably higher than would be obtained using dedicated machines.

3: Virtual Network Configuration for a Rapidly Deployable Network

In order to make RDRN truly rapid, configuration at all layers has to be a dynamic and continuous process. Configuration can

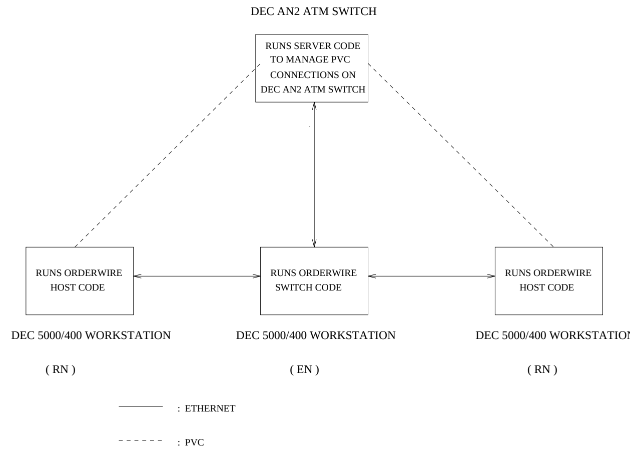

Figure 7. Physical Setup for PVC Timing.

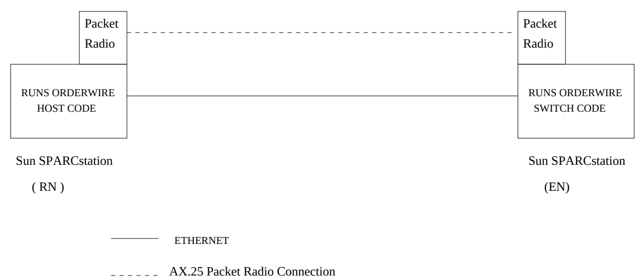

Figure 8. Physical Setup for Packet Radio Timing.

Event	**Time (ms)**
AN-2 VC Setup	300
VC_SETUP	476
USER_POS	677
NEWSWITCH	439
HANDOFF	473
MYCALL	492
SWITCHPOS	679
TOPOLOGY	664

Table 9. Network Configuration Timing Results.

be a function of such factors as load, distance, capacity and permissible topology, all of which are constantly changing in a mobile environment. A Virtual Time type algorithm can be used to anticipate configuration changes and speed the reconfiguration process.

3.1: Virtual Network Configuration Algorithm

The Virtual Network Configuration (VCN) algorithm is an application of a more general mechanism called Time Warp Emulation (TWE). Time Warp Emulation is a modification of Time Warp [9]. The following is a brief overview of TWE, followed by the VCN algorithm.

3.1.1: Time Warp Emulation

The motivation behind TWE is to allow a real-time system to work ahead in time by predicting future behaviour and adjusting itself when that behaviour does not match reality. This is accomplished by realizing that there are now two types of *false* messages, those which arrive in the past relative to the process's Local Virtual Time (LVT) and those messages which have been generated which are timestamped with the current real time, but whose values exceed some tolerance from the actual value.

Here the basic Time Warp mechanism is modified by adding a verification query phase. This phase occurs when real time matches the receive time of a message in the output queue of a process. In this phase the physical device being emulated is queried and the results compared with the value of the message. A value exceeding a prespecified tolerance will cause a rollback of the process.

3.2: Virtual Network Configuration Overview

The Virtual Network Configuration (VNC) algorithm can be explained by an example. A remote node's direction, velocity, bandwidth used, number of connections, past history and other factors can be used to approximate a new configuration sometime into the future. All actual configuration processes can begin to work ahead in time to where the remote node is expected to be at some point in the future. If the prediction is incorrect, but not far off, only some processing will have to be rolled back in time. For example, the beamsteering process results may have to be adjusted, but the topology and many higher level requirements will still be correct. This working ahead and rolling back to adjust for error with reality can be a continuous process, depending on the tradoff between allowable risk and amount of processing time allowed into the future.

As a specific example, consider the effects of handoff on TCP performance as described in [4]. In this work, throughputs were measured in Table 10.

Type of Handoff	Bandwidth
No Handoffs	100%
Overlapping handoffs	94%
0-second rendezvous delay	88%
1-second rendezvous delay	69%

Table 10. Bandwith Loss Due to Handoff.

Even a zero second delay in receiving handoff notification caused significant performance loss. In the Virtual Network Configuration System, the handoff will be precomputed which should result in performance at least as good as that shown for overlapping cells in [4].

3.3: Virtual Network Configuration Implementation

The effort required to enhance network configuration to include Virtual Network Configuration is minimal. Three new fields are added to each existing message: antimessage toggle, send time, and receive time. Physical processes include beamforming, topology acquisition, table updates, and all processing required for configuration. Each physical process is assigned a tolerance. When the value of a real message exceeds the tolerance of a predicted message stored in the send queue, the process is rolled back.

Also, an additional packet type was created for updating an approximation of the GVT. Since the network configuration system uses a master node as described in the physical layer setup, this is natural centralized location for a centralized GVT update method as well. RNs transmit their LVT to the master, the master calculates an approximate GVT and returns the result.

4: Summary

This work has presented the results of a working prototype network configuration system which uses GPS time and position to configure a wireless mobile ATM system.

A Virtual Network Configuration Algorithm was proposed to enhance the performance of the network configuration system. This algorithm is a simple modification of the network configuration system based on Virtual Time which allows the virtual network configuration system to both predict and prepare for network changes before they occur. This allows the constantly changing configuration to be as rapid as possible.

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