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A cell-numbering plan for seamless handoff in a wireless ATM network

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Abstract

This paper proposes a *cell-numbering plan* for mobile stations to handoff seamlessly to the cells in a wireless Asynchronous Transfer Mode (ATM) network. It also proposes a *minimum-hop rerouting* (MHR) method to perform the rerouting of user connections during the handoff. The cell-numbering plan assigns each cell an integer from 1 to 5, ensuring that neighboring cells will have different numbers. Any mobile station that performs a handoff beween any two cells can easily calculate if a reroute is needed. Furthermore, by using the MHR, the path between the originating and terminating mobile stations will be the shortest whenever either of them moves. The signaling bandwidth used for this kind of rerouting is believed to be the smallest among the methods reported to date.

Keywords: Handoff; Wireless networks; Asynchronous transfer mode; Rerouting

1. Introduction

Current Personal Communication Systems such as GSM or IS-41 are supported only by low-transmission-rate mobile data services. The new standards, such as *General Packet Radio Service* and *High Speed Circuit Switched Data*, can support a data rate from 9.6 to 28.8 kbps. However, most applications (e.g. the WWW, video conferencing and so on) require high-speed transmission. Thus, a wireless ATM [1–6] network is proposed to solve this problem. With the speed of new developments in wireless network systems and ATM networks, it is an exciting task to give mobile users access to broadband services anytime, anywhere, with anybody and in any form.

An important function of the wireless network is the handoff of mobile users. While a mobile user is moving across the radio cells of the personal communication system network, the mobile station (MS) exchanges radio signals with different base stations (BS). The handoff between the original BS and the new BS cannot be interrupted, so the call is continued. Especially in high-speed wireless ATM networks, if the service is either time-sensitive (e.g. voice and video) or loss-sensitive (e.g. file transfer), the user's radio link must not be interrupted. Thus, a seamless handoff is required for a high-speed network environment and the overhead for handoffs from BS to BS should be kept as small as possible.

A wireless ATM network is constructed as shown in Fig. 1. There is a BS in each cell. The MS exchanges its radio signal with the BS. The BS is connected to an ATM switch. Note that an ATM switch cover cells are grouped as a zone. The ATM switch is also the zone manager of this area. All ATM switches are connected as the backbone of the network. Any mobile user that wants to communicate with another user must use the BS and ATM backbone to transmit his messages.

The user is mobile and will move from time to time. When the user moves between two cells of the same zone, he can exchange radio signals with the new BS, and the zone manager (ATM switch) can update its virtual circuit translation table to make the incoming ATM data cells go to the new BS. A new connection is set up between the new BS and the ATM switch. This is called the *intra-zone handoff* and it does not involve other ATM switches. If the mobile user moves to new BS under the control of a new ATM switches (i.e. *inter-zone handoff*), the MS exchanges radio signals with the new BS and it sets up a connection to the new switch. The new switch must coordinate with the original switch to reroute the data cells. Moreover, more than two (original and current switches) switches may be involved in the rerouting. Whether it reroutes incoming cells to the MS or outgoing cells to the far end of the terminating MS, the ATM switches must use a high-quality rerouting method to ensure smooth cell transmission.

A few methods have been proposed to solve the rerouting of the wireless ATM networks [7–15]. The virtual connection tree (VCT) [8] sets-up connections in advance for the

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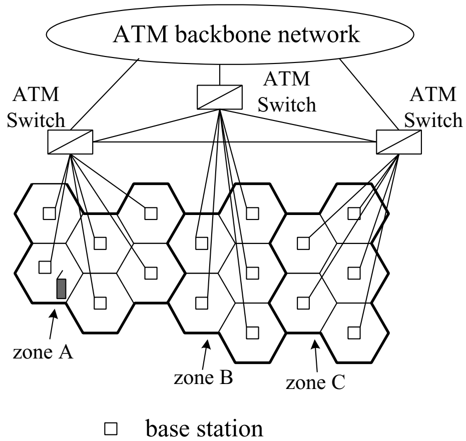

Fig. 1. A wireless ATM network.

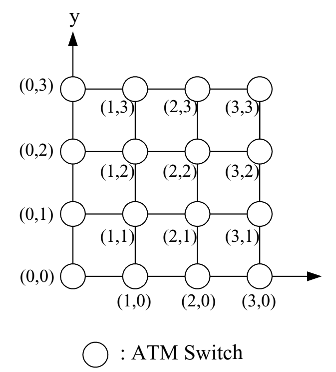

Fig. 3. Addressing of ATM switches (an example f 16 switches)

mobile stations. However, it wastes unused connections that are prepared only for the MS to handoff. The Source Routing Mobile Circuit (SRMC) Rerouting [14] uses a tethered point to support handoff during rerouting. The resource allocation process in SRMC involves exchanging many signaling messages in the network, and this wastes bandwidth. The Yuan–Biswas scheme [15] designates a handoff switch to perform rerouting and it forwards cells to their destinations. However, cell forwarding requires cells to be buffered and that is a burden on the network. The Nearest Common Node rerouting (NCNR) [7] uses the common node that is nearest to both ATM switches (i.e. before handoff and after handoff) in two zones to perform rerouting. The NCNR overcomes many drawbacks of the previous strategies, but the path after rerouting may not be the shortest. The methods proposed in this paper resolve both these flaws.

The authors believe that a well-planned network can reduce much of the effort later required to modify and expand the network. The network architecture proposed in this paper has the features of simplicity, modularity, and expandability. Both the proposed network architecture and the rerouting method are used to reduce the overhead (especially the signaling bandwidth) of handoff. A cell-numbering system, which assigns each cell an integer from 1 to 5

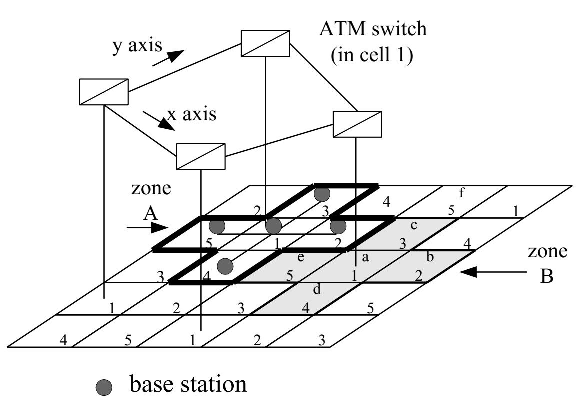

Fig. 2. Proposed network architecture.

such that neighboring cells have different numbers, is used. Any mobile station that takes a handoff between any two neighboring cells can know what kind of handoff (i.e. intrazone handoff or inter-zone handoff) it performs by using a simple calculation. Incorporated with the regular topology for ATM networks, the ATM switches can quickly find a minimum hops path for the user connection. Network resources such as switch processing, network bandwidth, and signaling for the exchange of messages will be reduced. The organization of this paper is as follows. Section 2 proposes the network architecture and novel rerouting strategy. Section 3 describes the implementation considerations. Section 4 shows the analysis and discussion while Section 5 is the conclusion.

2. Proposed network architecture and rerouting strategy

2.1. Architecture description

A novel, wireless ATM network architecture is shown in Fig. 2. The total area covered by the wireless network is divided into cells. Each cell has the shape of a rectangle or a circle, and is served by a base station (BS). A zone is a cross-shaped area and contains five cells. The zone manager is an ATM switch that is connected to the five BSs and can be at any one of the five cells in a zone. We assigned an integer from 1 to 5 for each BS. The rule of this assignment is that any two neighbors always have different numbers. For simplicity, we designated the ATM switch at cell 1. The ATM switches are connected as in a Manhanttan street graph (see Fig. 3). That is, each switch, except for the switches on the border of the network, is connected to its four neighboring switches.

The rule for numbering BSs is described as follows.

1. Initially, designate a cell as cell 1.
2. The numbering of the other cells can be obtained recurrently using the following method. For two adjacent cells *a* and *b*, if cell *a* has been numbered as *i*, then cell *b* is

Table 1
Mapping of the cell change and coordinate change

n_{i-1}	n_i	(x_i, y_I)
2	3	$(x_{i-1}+1, y_{i-1})$
2	4	$(x_{i-1}, y_{i-1}+1)$
2	5	$(x_{i-1}+1, y_{i-1})$
3	2	$(x_{I-1}-1, y_{i-1})$
3	4	$(x_{i-1}, y_{i-1}+1)$
3	5	$(x_{i-1}, y_{i-1}+1)$
4	2	$(x_{i-1}, y_{i-1}-1)$
4	3	$(x_{i-1}, y_{i-1}-1)$
4	5	$(x_{i-1}+1, y_{i-1})$
5	2	$(x_{i-1}-1, y_{i-1})$
5	3	$(x_{i-1}, y_{i-1}-1)$
5	4	$(x_{i-1}-1, y_{i-1})$

numbered as

$$j = \begin{cases} (i \bmod 5) + 1, & \text{if cell } b \text{ is at the right-hand side of cell } a, \\ (i + 1 \bmod 5) + 1, & \text{if cell } b \text{ is above cell } a, \\ (i + 2 \bmod 5) + 1, & \text{if cell } b \text{ is below cell } a, \\ (i + 3 \bmod 5) + 1, & \text{if cell } b \text{ is at the left-hand side of cell } a. \end{cases}$$

For example, cells *b*, *c*, *d* and *e* in Fig. 2 are numbered as cells 2, 3, 4 and 5, respectively. Cell *f*, which is above cell *c*, is numbered as 5 (i.e. $5 = (3 + 1 \bmod 5) + 1$).

After all cells are labeled, it was found that any two neighboring cells had different integers. We assume that each ATM switch was at cell 1. One can connect these ATM switches as a Manhattan street graph. A Cartesian coordinate (x,y) was used to label the ATM switches

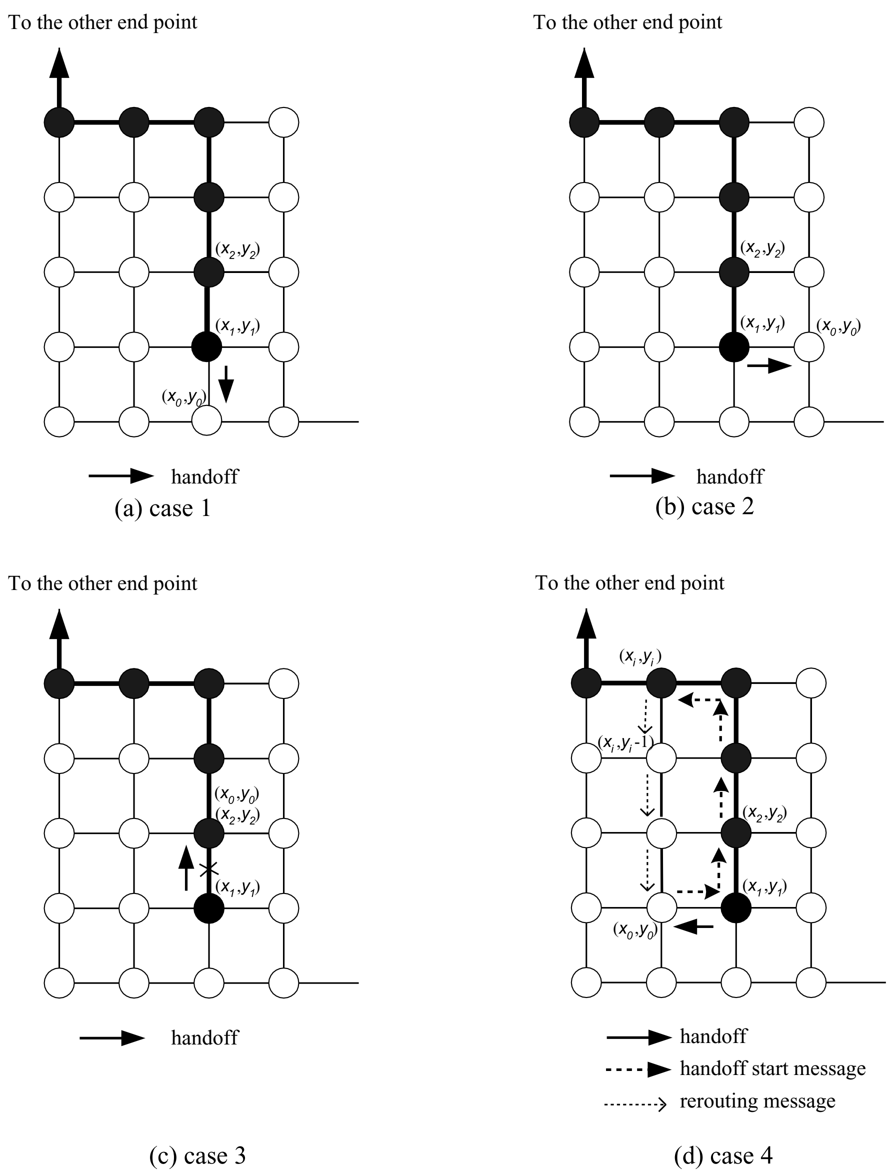

Fig. 4. Four possible cases of rerouting.

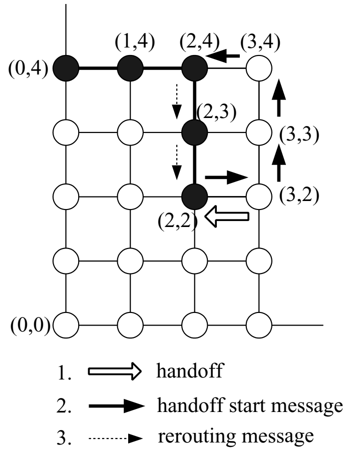

Fig. 5. An example of rerouting.

where (*x*,*y*) was the location of the switch in the graph. Fig. 3 shows an example of 16 switches in a network.

2.2. Minimum-hop rerouting

Initially, the MS can recognize its location (including cell number *n* and switch address (*x*,*y*)) by a registration process. Assume that the MS at ATM switch (x_{i-1}, y_{i-1}) and cell number n_{i-1} is moving to a new cell and receives a radio signal containing a new cell number n_i from the new BS. Then, MS can determine what kind of handoff it performs and which ATM switch (x_i, y_i) (present zone manager) it connects to by the following computation:

1. If $n_{i-1} = 1$ or $n_i = 1$, then the MS performs an intra-zone handoff and $(x_i, y_i) = (x_{i-1}, y_{i-1})$. That is, the MS moves out or moves in cell 1. The switch that it is connected to does not change.
2. If $n_{i-1} \in \{2, 3, 4, 5\}$ and $n_i \in \{2, 3, 4, 5\}$, then the MS performs an inter-zone handoff and the new zone manager (x_i, y_i) can be found from Table 1.

Assume, for example, the MS at switch (2,2), cell 2 (i.e. $n_{i-1} = 2$ and $(x_{i-1}, y_{i-1}) = (2, 2)$), is moving to cell 4. From Table 1, one can find the MS is moving to zone (2,3) (i.e. $(x_i, y_i) = (x_{i-1}, y_{i-1} + 1) = (2, 3)$). In this case, the MS performs an inter-zone handoff.

When an MS moves to a new zone, the route of this connection may need to be changed. The switch at the new zone is responsible for this rerouting. Because the Manhattan street graph is simple and regular, the nearest common node rerouting [7] can be done easier. In Minimum-hop rerouting (MHR), one can find a path with minimum hops for each ATM connection. For convenience, we denoted a connection between the originating MS and the terminating MS as $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$ where the originating MS connects to switch (x_1, y_1), and the terminating MS connects to switch (x_n, y_n). Moreover, assume that $x_1 \geq x_n, y_1 \leq y_n$ and $(x_2, y_2) = (x_1, y_1 + 1)$.

Because rerouting in the intra-zone handoff does not involve any other ATM switch, the following only discusses rerouting of the inter-zone handoff. When an originating MS is moving to a new zone managed by switch (x_0, y_0), the zone manager (x_0, y_0) checks the location of switch (x_1, y_1) and performs rerouting. There are four possible cases of rerouting for the MS (see Fig. 4).

1. If $x_0 = x_1$ and $y_0 < y_1$ (i.e. present switch (x_0,y_0) is below (x_1,y_1)), then switch (x_0,y_0) informs switch (x_1,y_1) and the new connection is setup without any further network involvement. Path $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$ is a minimum-hop path. Thus, the resulting path $(x_0, y_0), (x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$ is also a minimum-hop path (see Fig. 4(a)).
2. If $x_0 > x_1$ and $y_0 = y_1$ (i.e. the present switch (x_0,y_0) is at the right-hand side of (x_1,y_1)), similarly, switch (x_0,y_0) informs switch (x_1,y_1) and the new connection is setup without any further network involvement. Path $(x_0, y_0), (x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$ is a minimum-hop path (see Fig. 4(b)).
3. If $x_0 = x_1$ and $y_0 > y_1$ (i.e. the present switch (x_0,y_0) is above (x_1,y_1)), then switch (x_0,y_0) sends a message to (x_1,y_1), relaying the handoff request. Once the handoff is stable, (x_0,y_0) deletes the MS connection from itself to (x_1,y_1). The rerouting is completed and the new connection is $(x_2, y_2), \ldots, (x_n, y_n)$ (see Fig. 4(c)).
4. If $x_0 < x_1$ and $y_0 = y_1$ (i.e. the present switch (x_0,y_0) is at the left-hand side of (x_1,y_1)), then switch (x_0,y_0) sends the handoff start message along the path $(x_0, y_0), (x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$ until it reaches the first switch (x_i, y_i) with $x_i = x_0$. Then switch (x_i, y_i) is designated as the nearest common node (NCN). The NCN forwards a reroute message to all switches in the path $(x_i, y_i), (x_i, y_i - 1), (x_i, y_i - 2), \ldots, (x_0, y_0)$. The switches that receive the reroute message set up the necessary connection and circuit translation tables. When a rerouting message is received by (x_0,y_0), a reroute acknowledgment message is sent from (x_0,y_0) to (x_1,y_1). When the handoff is stable, switch (x_1,y_1) then sends a clear connection to (x_i,y_i) and connection $(x_1, y_1), (x_2, y_2), \ldots, (x_i, y_i)$ is cleared. The new connection $(x_0, y_0), \ldots, (x_i, y_i - 2), (x_i, y_i - 1), \ldots, (x_n, y_n)$ is a minimum-hop connection (see Fig. 4(d)).

Note that cases 1 and 2 just extend their routes, case 3 is moving back to its previous node, and case 4 needs to construct a new route. For example, consider case 4. As shown in Fig. 5, there is a connection $(x_1, y_1), \ldots, (x_n, y_n) = (3, 2), (3, 3), (3, 4), (2, 4), (1, 4), (0, 4)$ and the MS is moving from (3,2) to new switch $(x_0, y_0) = (2, 2)$. The handoff start message is sent by (2,2) via path (2,2),(3,2),(3,3),(3,4),(2,4). Switch (2,4) is the NCN because $x_i = x_0 = 2$. Then, (2,4) sends a rerouting message to (2,2) via path (2,4),(2,3),(2,2). The switches (2,4),(2,3),(2,2) set up the necessary connection and circuit translation tables. Then, (2,2) notifies (3,2) by a reroute acknowledgment message and (3,2) sends a clear connection to (2,4) to clear the connection

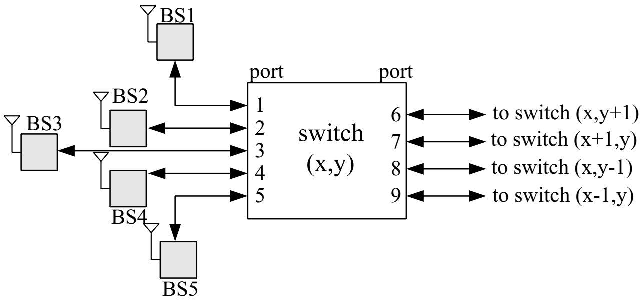

Fig. 6. An example of port layout for an ATM switch.

(3,2),(3,3),(3,4),(2,4). That is, after rerouting, the new connection (2,2),(2,3),(2,4),(1,4),(0,4) is established.

3. Implementation

This section proposes an implementation of the MHR in the ATM switch. Assume that each switch (*x*,*y*) has at least nine ports (see Fig. 6). We assigned ports 1, 2, 3, 4, and 5 to connect BSs 1, 2, 3, 4 and 5, respectively. Then assign ports 6, 7, 8 and 9 to connect switches $(x, y+1)$, $(x+1, y)$, $(x, y-1)$ and $(x-1, y)$, respectively. Every ATM switch contains a circuit translation table for performing cell routing. The circuit translation table consists of the incoming virtual connecting number (VCN_in) and incoming port (Port_in) for incoming cells, and also contains the outgoing virtual connection number (VCN_out) and outgoing port (Port_out) for departing cells. The mapping of (VCN_in, Port_in) and (VCN_out, Port_out) is for switching the cells belonging to the virtual connection in this ATM switch. For a virtual connection, from the originating switch through the terminating switch, including the intermediate switches, every switch in the route assists in building the circuit translation table. The addresses of the ATM switch can be included in the virtual connection number. For example, in a 4×4 network, one can use the first five bits *ddddd* of the virtual connection number to represent switch (*x*,*y*) (i.e. we can use the value $x \times 4 + y + 1$ to label switch (*x*,*y*) and *ddddd* is the binary number of $x \times 4 + y + 1$) and the other bits are assigned by switch when virtual connection is set up. Especially, *ddddd* = 00000 represents *this* switch.

Mobile connection rerouting in a Manhattan street graph is illustrated in Fig. 7. Assume that each switch is equipped with a VCN monitor and translator. Shown in the diagram are the VCNs associated with a single connection that terminates at switch (1,1). Suppose the MS connection is initially established in BS 5. The circuit translation tables of switches (1,1) and (0,1) are shown in Table 2.

Then, its ATM cells arrive at port 5 of switch (1,1) bearing 00110*ddd*, and are switched to port 9 where the connection number is translated to 00010*ddd*. These cells arrive next at port 7 of switch (0,1) and then are switched to port 6 and their connection number is translated to 00011*ddd*. In the reverse direction, the cells arrive at port 6 of switch (0,1) bearing 00010*eee*, and are switched to port 7 with their connection number changed to 00110*eee*. They next arrive at switch (1,1), port 9, and then are switched to port 5 and arrive at base station 5 bearing connection number 00000*eee*. Upon handing off to base station 1, the MS and base station know that this is an *intra-zone handoff*. Base station 1 set up a connection to switch (1,1) and then switch (1,1) modifies the circuit translation table (see Table 3) such that the cells arrive at port 1 (port 9) bearing connection number 00110*ddd* (00110*eee*) and are switched to port 9 (port 1). Their connection number is translated to 00010*ddd* (00000*eee*).

For inter-zone handoffs, consider the MS moves from base station 5 to base station 3. From Table 1, one finds that the MS moves to a new zone managed by switch $(x, y-1) = (1, 0)$. Since the new switch is below switch (1,1), path (1,0),(1,1),(0,1),… is also a path with minimum hops. Thus, switch (1,0) adds a connection to switch (1,1), directly. Two entries are added to the circuit translation table of switch (1,0), one for down stream and the other for up stream, as shown in Table 4. Switch (1,1) changes (VCN_in, Port_in) = (00110*ddd*,5) and (VCN_out, Port_out) = (00000*eee*,5) to (VCN_in, Port_in) = (00110*ddd*,8) and (VCN_out, Port_out) = (00101*eee*,8), respectively. The upstream for this connection now is 00101*ddd*,00110*ddd*, 00010*ddd*,00011*dd*,… and downstream is 00011*eee*, 00010*eee*,00101*eee*,00000*eee*.

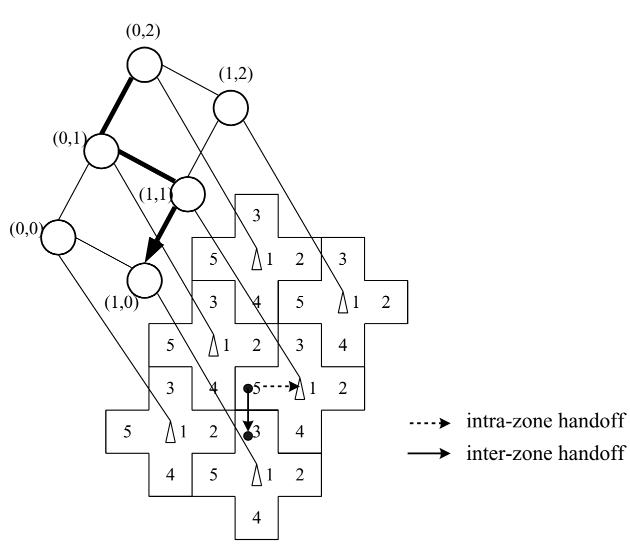

Fig. 7. An example of intra-zone handoff and inter-zone handoff.

4. Analysis and discussion

This section compares the MHR method with another up-to-date, best rerouting scheme. We used the same measurement characterizing method and simplifying measurement approach as in Ref. [7] for comparing with the NCNR

Table 2
The circuit translation tables of switches (1,1) and (0,1)

Switch (1,1)				Switch (0,1)			
VCN_in	Port_in	VCN_out	Port_out	VCN_in	Port_in	VCN_out	Port_out
00110*ddd*	5	00010*ddd*	9	00010*ddd*	7	00011*ddd*	6
00110*eee*	9	00000*eee*	5	00010*eee*	6	00110*eee*	7

Table 3
The circuit translation tables of switches (1,1) and (0,1) after an intra-zone handoff

Switch (1,1)				Switch (0,1)			
VCN_in	Port_in	VCN_out	Port_out	VCN_in	Port_in	VCN_out	Port_out
00110*ddd*	1	00010*ddd*	9	00010*ddd*	7	00011*ddd*	6
00110*eee*	9	00000*eee*	1	00010*eee*	6	00110*eee*	7

Table 4
The circuit translation tables of switches (1,1), (0,1) and (1,0) after an inter-zone handoff

Switch (1,1)				Switch (0,1)				Switch (1,0)			
VCN_in	Port_in	VCN_out	Port_out	VCN_in	Port_in	VCN_out	Port_out	VCN_in	Port_in	VCN_out	Port_out
00110*ddd*	8	00010*ddd*	9	00010*ddd*	7	00011*ddd*	6	00101*ddd*	3	00110*ddd*	6
00010*eee*	9	00101*eee*	8	00011*eee*	6	00010*eee*	7	00101*eee*	6	00000*eee*	3

instead of simulating a WAN by software simulator or hardware emulator. Because the rerouting scheme of MHR is similar to the NCNR scheme in a flat network, the number signaling messages exchanged during handoff (N_h) and number of signaling messages exchanged for rerouting during a handoff (N_r) are the same. However, MHR always keeps the connection with minimum hops but NCNR does not. In MHR, when the MS is moving to a new cell, it only has to listen to the cell number broadcast by BS and to immediately determine the new ATM switch address. Using the new ATM switch address, a new route for handoff can be more easily obtained. This reduces the time spent in finding a new route for handoff and the effort spent in previous and candidate switches.

Consider the average number of network nodes involved in rerouting (N_n) for MHR. Assume that any MS is equally likely to be found within any radio cell and the MS is moving from cell n_{i-1} to cell n_i. Note that the MS performs an intra-zone handoff when $n_{i-1} = 1$ or $n_i = 1$. The MS moves from cell 1 with a probability of $\frac{1}{5}$ and the probability for MS moving into cell 1 is $\frac{4}{5} \times \frac{1}{4}$. Then, an intra-zone handoff occurs with a probability of $\frac{2}{5}$ (i.e. $\frac{1}{5} + \frac{4}{5} \times \frac{1}{4}$.) The number of network nodes involved in rerouting for an intra-zone handoff is 1 and the numbers of network nodes involved in rerouting for cases 1, 2, 3 and 4 are 2, 2, 2, and D_1, respectively, where D_1 is a mean number of hops changed in the new path. Thus, N_n can be written as

$$N_n = \frac{2}{5} \times 1 + \frac{3}{5}\left(\frac{3}{4} \times 2 + \frac{1}{4} \times D_1\right) = 1.3 + \frac{3}{20} D_1$$

In NCNR, $N_n = 2$ for direct links while $N_n = 4 + D_2$ for no direct links where D_2 is the average number of hops from candidate switch to NCN. It depends on the network topology.

In MHR, there is only one connection used for rerouting (i.e. $N_c = 1$) and only basic bandwidth is allocated for the user connection, denoted as $B = 1$. The values of these two parameters are the same as NCNRs. These parameters are summarized in Table 5.

In the proposed network architecture, limiting the ATM networks with regular structure may not meet the traffic demand. However, the proposed network does work well

Table 5
Comparing rerouting algorithms

Measure	MHR	NCNR Direct link	NCNR No direct link
N_h	7	7	9
N_r	2	2	4
N_n	$1.3 + \frac{3}{20}D_1$	2	$4 + D_2$
N_c	1	1	1
B	1	1	1

in some situations, particularly those with uniform traffic or delay-sensitive traffic.

5. Conclusion

In the wireless ATM network, a well-planned network is required to reduce the impact of handoffs. The next-generation PCS network will support multimedia applications to mobile subscribers. Thus, networks must use the simplest and most efficient strategy to perform the rerouting during the handoff. This paper proposes a new architecture for how a wireless ATM network should be deployed and a simple but efficient strategy on how the ATM switches should perform rerouting. In this strategy, the number of signaling messages exchanged among the MS and ATM switches are fewer than those of other strategies. This means that rerouting is much quicker and easier to implement, thus meeting the requirements of high-speed ATM networks.

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