Architecture and Signaling Protocols for Wireless CATM Networks*

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Abstract

A frame-structure, referred to as CATM (CATv ATM), is introduced to serve as infrastructures of wireless networks. The widespread CATV (Community Antenna TV) networks are attractive infrastructures for next generation wireless networks. Providing interactive broadband services over CATV networks is also a big trend in communication and ATM (Asynchronous Transfer Mode) networks with broadband communication features well fit to be the backbone of CATV networks. Based on the proposed network architecture, the problems of call setup and handoff handling are addressed and investigated. A wireless signaling protocol for establishing mobile connections over the CATM-based wireless networks is proposed. To improve bandwidth utilization, keeping the resulting path after handoff as short as possible is attempted. A seamless handoff scheme (denoted as $SHS_{W\text{-}CATM}$), capable of preserving data continuity, transparent to other mobile terminals, and producing a shorter path, is also evolved. Analytic results reveal that the $SHS_{W\text{-}CATM}$ has a high probability to obtain an optimal resulting path (i.e., non-elongated path) after mobility [11].

Keywords: *CATV, ATM, Interactive broadband service, Handoff*

1. Introduction

Wireless personal communication services and interactive broadband services have rapidly grown to be two sizable parts of the world communication market. Extending multimedia services to portable terminals is an emerging requirement and motivates the integration of wireless technologies and broadband communications. Several relative works have been done to integrate wireless networks and ATM networks [6], [10], [12]. However, the large transmission speed difference of wireless network (1~20Mbps) and ATM network (155Mbps~Gbps) imposes great difficulties in integration. In the cost-effective point of view, the wide already existing CATV networks are ideal platforms for wireless networks, especially for micro-cellular or pico-cellular systems with small cell radius.

The CATV networks employ a tree-and-branch topology so as to gain salability, as shown in Fig. 1. A headend is located at the front end of the cable and acts as a gateway between the cable network and other networks (e.g., ATM). CATV networks are traditionally one-way, broadcasting, analog infrastructures for residential area TV distribution. However, the requirements of two-way interactive broadband services to home arise rapidly and promote several relative studies [7], [9]. Meanwhile, standardization activity has been aggressively undertaken by the IEEE 802.14 project [4] and DAVIC (Digital Audio Visual Council) [5]. Future CATV will provide two-way interactive broadband services. Several Medium Access Control protocols have been proposed for two way broadband services over the CATV networks [7], [9]. According to the features of CATV, it serves as a good infrastructure for wireless cellular networks and gains the following advantages. First, large infrastructure installation cost could be saved by utilizing CATV networks as it is already installed in many places with a very high bandwidth available. Second, the handoff handling in CATV networks is extremely simple and fast because of the broadcast and central control characteristics of CATV networks.

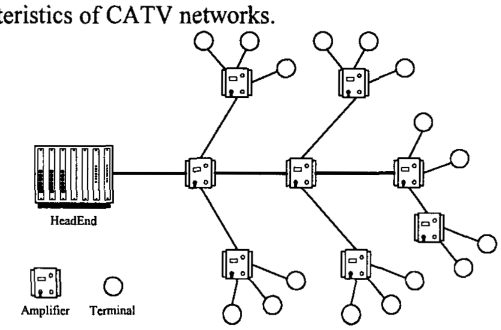

Fig. 1 Tree-and-branch structure of a typical CATV network.

In this paper, a two-tier wireless-CATM network as shown in Fig. 2 to provide broadband services to mobile terminals is introduced. Since ATM network is now viewed as an universal base technology for broadband networks and interactive broadband services to home gains great interests in industry, ATM serves as a good infrastructure for CATV networks. Hence, the proposed two-tier wireless CATM network first connects the wireless base stations via CATv networks and then ATM serves as the backbone of the CATV networks. The connection-oriented feature of ATM networks

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is quite different form those shared-medium access methods applied in LAN. In ATM networks, no data can be sent until a virtual channel connection (VCC) is established. In this paper, we investigate the issues of connection and mobility management for the proposed Wireless-CATM networks. A wireless signaling protocol is designed to set up a mobile connection and a seamless handoff scheme is also proposed. The rest of this paper is organized as follows. The system architecture is presented in Section 2. Section 3 addresses the required routing databases and the proposed wireless signaling protocol. The $SHS_{W\text{-}CATM}$ is described in Section 4. Finally, some concluding remarks are made in Section 5.

2. System Architecture

2.1 The CATM Network Architecture

In order to make a good integration of CATV networks and ATM networks, several MAC protocols have been proposed to be ATM compatible and ATM cells can be transported in those CATV networks [7], [9]. The CATM networks also employ an ATM compatible MAC protocol to simplify the gateway (headend) functions. Furthermore, the virtual channel connection, which is identified by a sequence of virtual path identifier/ virtual channel identifier (VPI/VCI), is extended to CATV networks. That is, a CATV station can setup a direct VCC to an ATM node or another CATV station. To facilitate further the headend's functionality, all VCCs' information (i.e., VPI/VCI) is forwarded from the headend to the CATV stations. Then, all traffic which is transferred from a CATV network to the ATM network can be prepared by the CATV stations and formed as ATM cells with the corresponding VPI/VCI. Thus, no VPI/VCI value conversion is required in the headend. This extremely simplifies the headend's work load, since the segmentation and re-assembly functions are totally eliminated. For the traffic of the other direction, the headend maintains a routing database with VCCs and the corresponding station addresses mappings. Whenever the headend receives an ATM cell from ATM interface, it use the cell's VPI/VCI as index to find the corresponding CATV station's address. Next, it forwards the cell to the corresponding station.

2.2 The Wireless CATM Architecture

A wireless CATM network is intended to extend integrated broadband services to the mobile terminals (MT) as illustrated in Fig. 2. For a wireless network, the serving area is partitioned into a number of *basic service areas* named as *cells*. Each cell is served by a BS, which exchanges radio signals with MTs. Mobility is a key feature of wireless networks. In order to provide mobility, tracking the locations of MTs becomes an important and primary function of wireless network and some databases are introduced to support such a capability. In the wireless CATM network, each CATV network covers a large geographical size and consists of a number of BSs. The areas served by the set of BSs which are interconnected via the same CATV network is commonly referred to as a *wireless community*. A set of wireless communities, which are connected via the same ATM switch, forms a *wireless cluster*. Each wireless cluster maintains a *wireless cluster manager* (WCM) to manage the BSs and MTs in its cluster. The WCM is responsible for database and connection management for the MTs in its cluster. The databases of WCM store subscriber location information, authentication information, and other information. Since the mobility management is the primary concern of this paper, the authentication and other functions are not addressed in this paper. The location database of WCM is broke into two parts: one is for the MTs which are permanently registered in the community, i.e., the "home" community (denoted as *home part*); the other one is for the MTs which are "visiting" the community (denoted as *visiting part*). We refer to the WCM as the *home WCM* of those MTs in its home part. The WCM must keep track of the location of the MTs in its home part. Let the identifier of an MT (denoted as MID) consist of the location information of its home WCM. To locate an MT, the BS first inquires its local WCM, denoted as WCM_l, (i.e., the WCM in its cluster). If the desired information is not found, the home WCM of the corresponding MT, denoted as WCM_h, is then queried. Such a database architecture is commonly referred to as the "two-tier database architecture". Similar designs can be found in the European GSM and U.S. IS-41 digital cellular standard. A virtual connection can be pre-established between the WCM and the BSs in its cluster for fast query transferring. How to design and implementation of WCM is an interesting issue and is going to be addressed in the future study.

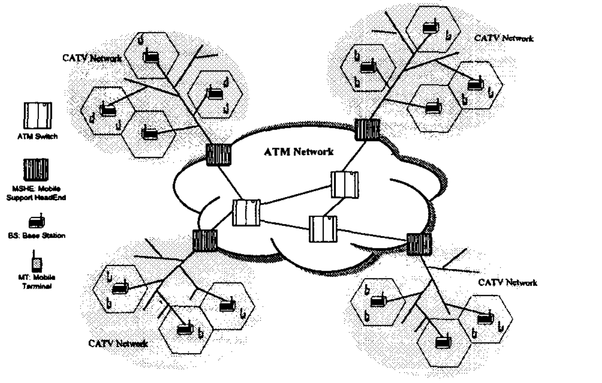

Fig. 2 The Wireless CATM network architecture.

For simplicity, a connection between a pair of MTs refers to as mobile connection (MC) and is identified by the source and destination MT identifiers. Based on the wireless CATM network, the MC is generally classified into two categories: Intra- and Inter-community MC. Intra-community

MC refers to the MC where the pair of communicating MTs resides in the same community; otherwise, it is an inter-community MC. For inter-community MC, since the data is transferred through ATM networks and the connection-oriented characteristic of ATM network, a direct VCC between the corresponding headends is required for data transportation. Furthermore, the VCC is extended to the CATV network, that is, the headends would forward the VCC information to the corresponding BSs. However, although, the traffic of an intra-community MC is transferred within a CATV network, establishing a VCC to deliver the intra-community MC's traffic is highly desired as its mobile characteristic. This can simplify the handoff procedure while an intra-community MC becomes an inter-community MC because of mobility. The VCC using by an MC is commonly referred to as a *Mobile VCC* (MVCC). The MVCC may reside in CATV network only (for intra-community MC) or both CATV and ATM networks (for inter-community MC). The MVCC could be setup via the wireless signaling protocol which is adapted from the ATM signaling protocol [1] and going to be described in the next section. The headends of the wireless CATM network should be capable of processing the message of wireless signaling protocol and maintaining all the currently active MVCCs in its community so as to provide wireless communication over CATM networks. We refer to the headend with such mobile ability as mobile supported headend (MSHE). To distinguish the wireline and wireless services, using a specific signaling VCC for wireless service with a VPI/VCI different from the predefined VPI/VCI value (VPI=0, VCI=5) for wireline services is highly desired. Thus, the MSHE can proceed the proper wireless signaling processes immediately without any further identification. For seamless handoff, a handoff VCC (denoted as HVCC) is also pre-established between all MSHEs in the CATM network to carry the handoff messages.

3. Wireless Signaling Protocol

Recall that an MVCC is established for both intra- or inter-community MCs. Furthermore, to provide seamless handoff, we maintain an individual MVCC for each MC instead of a virtual connection for each wireless LAN or a pair of BSs [10]. This way can simplify the mobility transparency and the elongated path reduction.

3.1 Routing Databases

Before introducing the wireless signaling protocol, the following four routing databases within BSs, MSHEs, and ATM switches are necessitated so as to provide wireless communication over wireless CATM networks.

BS Registration Database: Each BS maintains a BS registration database to record all the MTs within its serving cell. An MT, while moving to a new cell, registers with its MID to the new BS and the old BS deletes the corresponding entry form its registration database.**BS Routing Database (BRD)**: For data forwarding, a BS has to record the routing information for currently active MCs. Since each MC (identified by the source-destination MID pair) is served by an individual virtual connection, the BS has to record an MID pair-VCC mapping for each MC.

MSHE Routing Database (MRD): At each MSHE, the incoming VCC (IN-VCC) and incoming port (IN-PORT) of an arriving ATM cell are used as indices in the MRD to uniquely identify the outgoing VCC (OUT-VCC) and the outgoing port (OUT-PORT). If the outgoing port is a CATV interface, an outgoing CATV address (OUT-ADD) is necessary. Thus, a mapping tuple (IN-PORT, IN-VCC, OUT-PORT , OUT-VCC, OUT-ADD) is kept in the MRD for each currently active VCC.

ATM Switch Routing Database (ASRD): At each ATM switch node, the incoming VCC (IN-VCC) and incoming port (IN-PORT) of an arriving ATM cell are used as indices in the ASRD to uniquely identify the outgoing VCC (OUT-VCC) and the outgoing port (OUT-PORT). Thus, a mapping tuple (IN-PORT, IN-VCC, OUT-PORT, OUT-VCC) is held in the ASRD for each currently active VCC. Whenever a virtual connection is setup through the signaling protocol, a new mapping tuple is inserted into the ASRD of each ATM switch along the path.

3.2 Mobile Connection Setup Procedure

In this subsection the procedure of establishing an MC which can be adapted from the ATM signaling protocol is described. For simplicity, some notations are defined firstly. Let the originator (terminator) MT of a mobile connection denote as MT_o (MT_t). The base stations of MT_o and MT_t are referred to as BS_o and BS_t, respectively. The BS_o and BS_t connect to MSHEs HE_o and HE_t, respectively. Notably, both BS_o and BS_t reside in CATV networks, therefore, they have CATV network addresses CATV BS_o and CATV BS_t. Similarly, since HE_o and HE_t attach to ATM switches directly, they have ATM network addresses ATM HE_o and ATM HE_t. The following messages are needed to set up a mobile connection.

Call-Request Message: MT_o sends a Call-Request Message with the MIDs of MT_o and MT_t to its base station BS_o, to setup a mobile connection

Location Message: BS_o issues a Location query to its local WCM to find the location of MT_t. If the local WCM dose not hold the location information of MT_t, BS_o inquires further the home WCM of MT_t to get the addresses of MT_t's BS and MSHE.

Setup Message: The Setup Message is adapted from the ATM signaling protocol. This original ATM Setup Message includes required bandwidth, Quality of Service (QoS) parameters, and the source/destination ATM addresses. In order to construct a mobile connection, the source/destination ATM addresses are adapted to (MT_o/CATV BS_o/ATM HE_o;

MT_t/CATV BS_t/ATM HE_t). An Setup Message with ($MT_o/BS_o/HE_o$; $MT_t/BS_t/HE_t$; required bandwidth; OoS parameters; …) is sent by BS_o to the HE_o so as to setup an MC. While a VCC is set up between HE_o and HE_t, HE_t forwards further the Setup Message with the corresponding VPI/VCI to BS_t to form an MVCC.

Connect (Reject) Message: The Connect (Reject) Message, adapting from the ATM signaling protocol, is a positive (negative) reply for a connection establishment. It is sent by BS_t to HE_o to indicate the MC's acceptance (rejection). Remarkably, while HE_o receives the Connect Message, it would pass further the Connect Message to BS_o with the corresponding MVCC information. BS_o, while receiving a Connect Message, enters the corresponding MC-VPI/VCI mapping into its BRD for data forwarding.

Connect-Ack Messages: A Connect-Ack Messages is sent by BS_o to BS_t to acknowledge the successful connection setup.

Call-Reply Message: BS_o sends a Call-Reply Message to MT_o to notify call acceptance.

The procedure to set up an MC is stated as follows.

Step 1: When MT_o is going to set up an MC with MT_t, it issues a Call- Request Message with (MT_o; MT_t) to BS_o.

Step 2: The BS_o then issues a Location Message with (MT_t) to its local WCM to get the addresses of MT_t's BS and MSHE. If the desired information is not found in the local WCM, BS_o inquires further the home WCM of MT_t.

Step 3: After BS_o gets the location of MT_t, it sends an Setup Message with (Mt_o /CATV BS_o /ATM HE_o; MT_t /CATV BS_t /ATM HE_t; required bandwidth; QoS parameters; …) to HE_o.

Step 4: HE_o, while receiving the Setup Message, checks whether the MC is an intra-community connection or not according to the addresses of HE_o and HE_t. The necessitated processes are described in the following two cases.

Case **Intra-community connection**: For an intra-community connection, HE_o assigns a pair of VPI/VCI values to set up an MVCC for the MC and then forwards the MC(MT_o, MT_t)-VPI/VCI mapping to BS_t.

Case **Inter-community connection**: If the connection is an inter-community MC, HE_o would initiate the ATM signaling protocol to set up a VCC from HE_o to HE_t. Meanwhile, the MTs' identifiers and BSs' addresses (i.e., Mt_o /CATV BS_o; MT_t/CATV BS_t) are also appended as parameters so as to extend the VCC (from HE_o to HE_t) within ATM networks to an MVCC (from BS_o to BS_t) over CATM networks. Thus, while the VCC is determined, the HE_t should pass the MC(MT_o, MT_t)-VPI/VCI mapping to BS_t to germinate an MVCC.

Step 5: After BS_t receives the MC(MT_o, MT_t)-VPI/VCI mapping, it pages the called party MT_t.

Step 6: The mobile terminal MT_t then replies with acceptance or reject.

Step 7 While BS_t receives MT_t's reply, it sends back a Connect or Reject to HE_o. Furthermore, if the reply is acceptance, BS_t also enters the MC(MT_o, MT_t)-VPI/VCI mapping into its BRD.

Step 8: HE_o forwards the received Message to BS_o. If the received message is Connect, HE_o also passes the MC(MT_o, MT_t)-VPI/VCI mapping to BS_o. BS_o, while receiving the Connect Message, sends a Connect-Ack Message to BS_t, inserts the MC(MT_o, MT_t)-VPI/VCI mapping into its BRDs, and starts the data transmission of MC(MT_o, MT_t).

Step 9: Once BS_t receives the Connect-Ack Message, it starts the regular data exchange for MC(MT_o, MT_t). A mobile connection with its MVCC is thereby established.

Finally, if the call is completed, the MVCC is released by using the Release and Release-Complete Messages adapted form the ATM signaling protocol. The signaling flow of establishing an MC is summarized in Fig. 3.

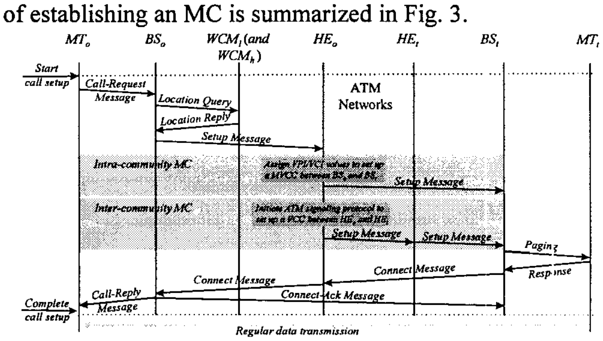

Fig. 3 Signaling message flow for mobile connection setup.

4. Seamless Handoff Procedures

In this section, the $SHS_{W\text{-}CATM}$ is described formally. In the wireless CATM network, the mobility is generally classifies into three categories: intra-community, intra-cluster, and inter-cluster mobility. The intra-community mobility means that an MT moves from C_i to C_j where C_i and C_j reside in the same community (i.e., C_i and C_j are served by the same MSHE). Suppose that C_i and C_j are in different communities but the MSHEs of C_i and C_j connect to the same ATM switch, such a mobility is commonly referred to as an intra-cluster mobility. Otherwise; it is an inter-cluster mobility. A handoff procedure is proceed to handle the required processes whenever a mobility occurs on an active MT (i.e., the MT is currently in communications). The design of the $SHS_{W\text{-}CATM}$ attempts to keep *data continuity*, *transparent to other MTs*, and *less routing effort*.

4.1 Intra-Community Mobility

This subsection describes the procedure to handle an intra-community mobility. Before introducing the intra-community handoff, some notations are defined firstly. Without a loss of generality, assume that a roaming MT (denoted as MT_R) moves from an original cell to a new cell where $BS_{original}$ (BS_{new}) is the base station of the original (new) cell, respectively. The $BS_{original}$ (BS_{new}) connects to headend $HE_{original}$ (HE_{new}); and the $HE_{original}$ (HE_{new}) attaches to ATM switch $SW_{original}$ (SW_{new}) further. In order to provide seamless handoff, some handoff messages are defined and discussed as follows.

Address Message: The MT_R emanates an address query to get the BS's CATV network address and the ATM address of the corresponding MSHE of the new cell (CATV BS_{new} /ATM HE_{new}). Next, the MT_R sends them to $BS_{original}$ via an Address Message: (CATV BS_{new} /ATM HE_{new}) to initiate a handoff procedure.

Routing Message: The $BS_{original}$ sends a Routing Message: (CATV $BS_{original}$ /ATM $HE_{original}$; CATV BS_{new} /ATM HE_{new}; MT_R -associated MCs' information) to $HE_{original}$. The $HE_{original}$ could identify whether the handoff is intra-community mobility or not. If it is an intra-community mobility, the $HE_{original}$ alters the corresponding tuples of each MC in the MRD for path modification.

Couple Message: After the MSHE $HE_{original}$ finishes the modification of its MRD, it sends a Couple Message: (MT_R -associated MCs' information) to BS_{new}.

Assume that a mobile terminal MT_R makes an intra-community mobility. The following steps are proceeded to handle the intra-community handoff.

Step 1: MT_R inquires BS_{new} to get the addresses of BS_{new} and HE_{new}. Next, MT_R issues an Address Message with (CATV BS_{new} /ATM HE_{new}) to $BS_{original}$.

Step 2: $BS_{original}$, while receiving the Address Message, sends a Routing Message with (CATV $BS_{original}$ /ATM $HE_{original}$; CATV BS_{new} /ATM HE_{new}; the MT_R -associated MCs' information) to $HE_{original}$.

Step 3: According to the received Routing Message, $HE_{original}$ determines whether the mobility is an intra-community handoff or not. If it is an intra-community mobility, $HE_{original}$ simply modifies the corresponding tuples in its MRD for path migration (from $BS_{original}$ to BS_{new}).

Step 4: After $HE_{original}$ completes the routing database modifications, it sends a Couple Message with the MT_R -associated MCs' information to BS_{new}.

Step 5: BS_{new} inserts the MT_R -associated MCs' information into its BRD and re-start the regular data transmission of MT_R.

The procedure of handling an intra-community handoff is summarized in Fig. 4.

4.2 Intra-Cluster Mobility

An intra-cluster mobility means that the MSHE of the new cell is different from the original one (i.e., $HE_{original} \neq HE_{new}$), but they attach to the same ATM switch (i.e., $SW_{original} = SW_{new}$). The handoff procedure of intra-cluster mobility is similar to that of intra-community mobility. However, since $HE_{original} \neq HE_{new}$ and $SW_{original} = SW_{new}$, the path modification should be completed by $SW_{original}$ instead of $HE_{original}$. Thus, $HE_{original}$ would forward the Routing Message to $SW_{original}$, and $SW_{original}$ then assigns a new VPI/VCI value for each MC. After $SW_{original}$ completes the path modification, it sends a Couple Message to HE_{new} and HE_{new} then forwards it to BS_{new}. Since HE_{new} does not know which the base station of the new serving cell is, the Couple Message augments one more parameter - the CATV network address of the new serving base station (i.e., *CATV* HE_{new}). The steps of disposing an intra-cluster handoff are stated in Fig. 5.

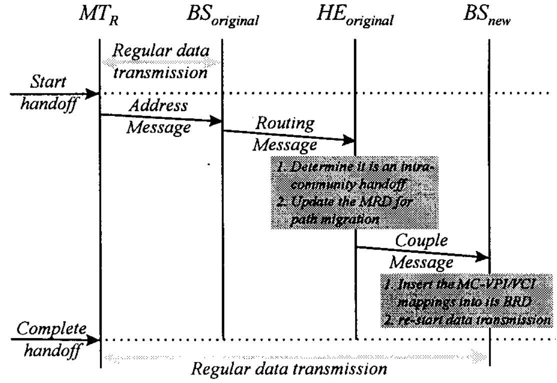

Fig. 4 Signaling message flow for intra-community handoff of the $SHS_{W\text{-}CATM}$.

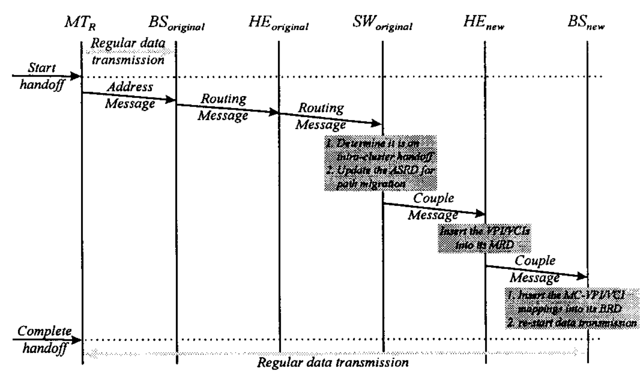

Fig. 5 Signaling message flow for intra-cluster handoff of $SHS_{W\text{-}CATM}$.

4.3 Inter-Cluster Mobility

For an inter-cluster mobility, since the new MSHE attaches to a ATM switch different from the original one (i.e., $SW_{original} \neq SW_{newl}$), a new MVCC from the ATM switch $SW_{original}$ to BS_{new} should be established for each MC. Remarkably, the new established MVCC begins from the $SW_{original}$ instead of the original MSHE or the original BS, this can reduce the elongated path. However, the new established

MVCC may produce a redundant loop (i.e., OUT-PORT=IN-PORT) within the ATM switch. In such a circumstance, an Elimination message is issued by the ATM switch which detects the redundant loop to the adjacent switch or MSHE. The Eliminate Message is defined as follows.

Elimination Message: Whenever an ATM switch detects that the input port is equal to the output port, it emanates an Eliminate message with the corresponding IN-VCC and OUT-VCC to the adjacent ATM switch. Moreover, it releases the redundant segments of the associated MVCC and removes the corresponding entries from its ASRD. The details of an inter-cluster handoff are described in Fig. 6.

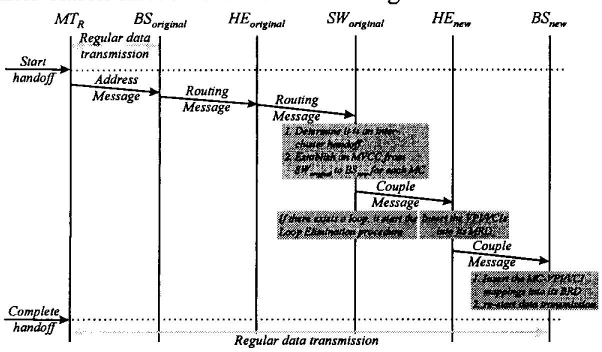

Fig. 6 Signaling message flow for inter-cluster handoff of $SHS_{W\text{-}CATM}$.

Remarkably, for an intra-community (intra-cluster) mobility, only the contents of MRD (ASRD) are updated in the MSHE (ATM switch) for path migration. Thus, the confirmation (Couple Message) is sent to BS_{new} in a batch way. However, for an inter-cluster mobility, the handoff time might be significantly long because the ATM switch should establish an MVCC for each MC. While n is large, the handoff procedure consumes a long time. Therefore, paralleling the path establishment and confirmation is highly desired. The confirmation should be sent to BS_{new} immediately, once an elongated path has been established. Meanwhile, the data transmission for the corresponding MC is re-started.

5. Conclusions

In this paper, a wireless CATM network has been proposed for supporting multimedia communication to mobile terminals. The issues of call setup and mobility handling over the wireless CATM networks have been addressed and investigated. We have proposed a database architecture to support mobility in wireless CATM networks. In this paper, the wireless signaling protocol, which is adapted from the ATM signaling protocol to establish mobile connections in the wireless CATM networks is evolved. We have also designed a seamless handoff scheme, which satisfies the data continuity and transparency requirements. The proposed seamless handoff scheme produces an optimal path (i.e., non-elongated path) for both intra-community and intra-cluster handoff. For inter-cluster handoff, it also makes the resulting communication path as short as possible. The analytic results show that the probability of obtaining an optimal resulting path for $SHS_{W\text{-}CATM}$ is significantly higher than that of $HS_{W\text{-}ATM}$ [11].

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