Protocol Design of Handoff Control in Mobile ATM networks

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February 15, 1998

Abstract

This paper studies handoff control mechanisms based on a 'Mobile ATM' concept. Mobile ATM refers to an ATM infrastructure that supports user mobility functions through an enhanced set of ATM signaling procedures within ATM backbone network. The authors present a protocol design suitable for alternative handoff control procedures in various situations, such as ATM/non-ATM accessses and different path re-routing algorithms. A signaling syntax is defined for the proposed protocol and a detailed signaling sequence is described. A prototype system is implemented based on this protocol, which provides an IP-over-ATM service with WaveLAN access.

1 Introduction

In recent years, two networking technologies – ATM and wireless, have penetrated rapidly because of the growing consumer demand for broadband and mobile wireless services, respectively. Due to the superior cost performance and QoS support provided by ATM switching technology, ATM is widely used as the backbone network for future integrated telecommunication infrastructures. Therefore, services accessed through wireless access technologies must inter-operate with ATM networks in order to have a wide area inter-networking capability. The 'Mobile ATM' concept [1] is such an idea that allows an ATM backbone network to support mobile services independent of the wireless access technologies.

A mobile ATM network is a regular ATM network with wireless access points (base stations) plus *mobility support extensions* in the ATM protocols. Two basic mobility functions must be supported: (1) location management – locating users during connection establishment and (2) handoff control – dynamic re-routing of mobile connections as users move. A mobile ATM network can be used to provide infrastructure for one or more existing wireless access method, such as GSM, PHS, TDMA or CDMA. The same mobile ATM network can evolve towards a "wireless ATM" network which supports end-to-end broadband ATM services. The motivation for the mobile ATM concept is to provide a common infrastructure to serve a diverse set of mobile services in the near term [2], while migrating to broadband end-to-end wireless ATM services [3] in the long term.

This paper studies handoff control in mobile ATM. Most previous work on this issue has focused primarily on the design of protocol extensions [4, 5, 6, 7, 8, 9]. The protocols were designed to meet different kinds of performance criteria such as, complexity, delay, latency and/or network resource utilization. These criteria largely depend on the properties of the access network such as, network topology, cell size, and supported service classes. Since the design of a mobile ATM network should be flexible enough to fit the variations of access networks, a generic handoff control protocol which can adapt the network properties is desired. In section 2, we define handoff control functions and classify the alternative handoff control procedures. In section 3, we propose a protocol with generic signaling mechanism which supports alternative path re-routing algorithms. For different re-routing algorithm, such a mechanism can provide (1) a common software architecture for system implementation, (2) a common measurement base for performance evaluation and (3) a common signaling syntax for standardization. We especially discuss the COS (crossover switch) discovery problem in section 4. An extension of PNNI routing is proposed for COS discovery process with low computational cost. In section 5, we present a software architecture of the mobile ATM system for the implementation purpose. The protocol stacks and signaling control modules on mobile terminals, base stations and ATM switches are discussed. We have implemented a prototype system based on a simplified version which supports IP-over-ATM through WaveLAN access. With this prototype, we have measured and compared the latency of new call's establishment and handoff call's re-routing.

2 Handoff Control Protocols in Mobile ATM

2.1 Wireless Access of Mobile ATM

A mobile ATM network architecture [1, 10, 11, 2] consists of wireless access ports(basestations) along with components of a standard ATM network, such as switches and fixed terminals interconnected via wire-line links. In this network architecture, basestations provide connectivity to mobile terminals via a wireless access link (e.g., radio).

In order to provide a generic interface to various wireless technologies, we propose to use a *Proxy Signaling Agent* (PSA) [12] on every basestation of the mobile ATM network. If the wireless access is non-ATM, the ATM network terminates at base stations. In this case, the PSA runs ATM UNI signaling to the network on behalf of mobile terminals. The PSA is responsible for multiplexing and converting the *Mobile Signaling* (MobSig) messages into the M-UNI interface to the ATM network, as shown in Figure 1. When a call arrives (departs) from a mobile terminal, the PSA will handle the corresponding MobSig message and add (delete) a route between the wireless NIC and the ATM NIC. The route bridges wireless packets and ATM cells with necessary conversion.

If the wireless access is ATM, the ATM network is end-to-end to wireless terminals. In this case, each basestation acts as an ATM switch which routes ATM cells between WATM NIC and ATM NIC. Since, in general, a basestation runs no PNNI routing, we can still consider the signaling controller on the basestation is a PSA on behalf of multiple mobile terminals. Instead of multiplexing/converting mobile signaling messages to M-UNI messages in non-ATM access, a PSA on WATM basestation will multiplex/convert M-UNI messages to M-NNI messages. With this common PSA scenario, both ATM and non-ATM wireless accesses can be supported within a single framework, any mobile service can be provided through plugging in a wireless interface card and running a message/data conversion subroutine in the PSA. This is exactly our view of a mobile ATM architecture.

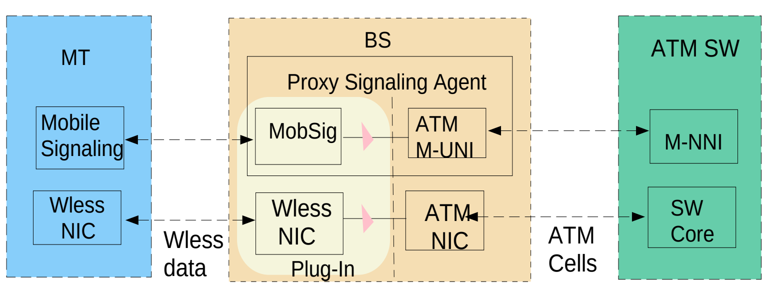

Figure 1: Wireless Access of Mobile ATM

2.2 Handoff control functions and protocols

Because handoff is a more frequent activity than call setup, it is necessary for the handoff to be faster and lighter weight than a regular connection establishment process. On the other hand, because handoff is a geographically local activity, it is also possible for a handoff to be completed faster and cheaper than a regular connection establishment. It is well accepted that instead of re-establishing a new connection path, an incremental path re-routing process should be applied for each handoff request [4, 5, 6, 7, 8]. The following definitions describe the functional requirements of a handoff control based on the incremental path re-routing process.

Capability: A handoff control process enables a mobile ATM network to seamlessly re-route the path of a connection between a mobile terminal and a correspondent terminal when the mobile terminal moves from one wireless access point to another wireless access point.

Participating Entities: The network entities involving a handoff control process can be illustrated in Figure 2. They are (1) Mobile Terminal (MT). (2) Corresponding Terminal (CT): the host at the other end of the connection. In most of cases, it is not aware the handoff control procedure. (3) Original Base Station (OldBS): it covers the cell where MT is currently in. (4) New Base Station (NewBS): it covers the cell where MT is about to enter. (5) CrossOver Switch (COS): the divergence point of the current connection path and a new connection path through the NewBS.

Primary functions: A handoff control process requires following primary functions to maintain the connectivity of a mobile user in the network: (1) Handoff initiation, (2) selection of a path re-routing algorithm, (3) a COS discovery process to find the COS,(4) establishment of a new path (NewPath) between COS and NewBS, (5) Replacement of the old connection path (OldPath, between COS and OldBS) with the NewPath and (6) Release of the OldPath.

Various protocol designs for handoff control process have been proposed

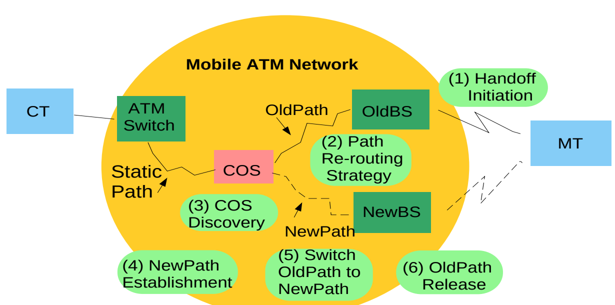

Figure 2: Handoff control functions and participating Entities

[6, 5, 7, 8]. They differ in the alternative methods of handoff initiation, path re-routing and COS discovery.

Handoff initiation:

The initiation of the handoff control process may be made when the connectivity is lost or the power level is below a certain threshold which indicates a fading. In the first case, the mobile terminal must choose a new basestation through wireless control process, similar to acquiring a new registration, and then send a handoff request directly to the NewBS. We call this *NewBS (Handoff) Initiation*. In the second case, a handoff request can be sent to the mobile's current basestation (OldBS) through the existing signaling channel. We call this *OldBS (Handoff) Initiation*. NewBS Initiation and OldBS Initiation are also called *Forward Handoff* and *Backward Handoff* [8]. We avoid this somewhat confusing terminology.

Path re-routing algorithm:

The key feature of a handoff control protocol is the path re-routing algorithm being used. It determines the complexity of the control procedure and the performance of a handoff connection. Depicted in Figure 3, a connection to be handed off is re-routed at a crossover switch (C0S) between the NewPath and the original path. A COS can be selected all the way along the original connection path, from the first switch (OldBS) to the last switch attached to the other end user (CT), depending on which performance criterion is used. The performance criteria could depend on (1) the complexity of the algorithm used to identify the COS, (2) the latency/delay to re-route the connection path and (3) the efficiency of the new connection path.

It is an essential design problem for a handoff control protocol to choose the correct type of COS according to the properties of the access network and the performance criteria. For examples, to reduce complexity, the OldBS may always be selected as the COS. This is called a *Path Extension* switch. To optimize the new path, the *Last Divergence* switch of two paths – the original path and a path from the NewBS to the CT is selected to give optimal connection paths after handoff.

COS discovery:

For a given connection, a given type of COS can be discovered through an extended ATM signaling procedure. Since the COS is a common switch on both the OldPath and the NewPath, the ATM signaling for COS discovery can be sent along with either the original connection path or the NewPath (while it is being set up). We call them *OldPath COS Discovery* and *NewPath COS Discovery*, respectively.

Since the NewPath COS Discovery is signaling along a path other than the original connection path, the original connection can only be identified by introducing a global connection ID (GCID). In current ATM UNI/NNI signaling specifications, there is no such ID being supported. However, it is

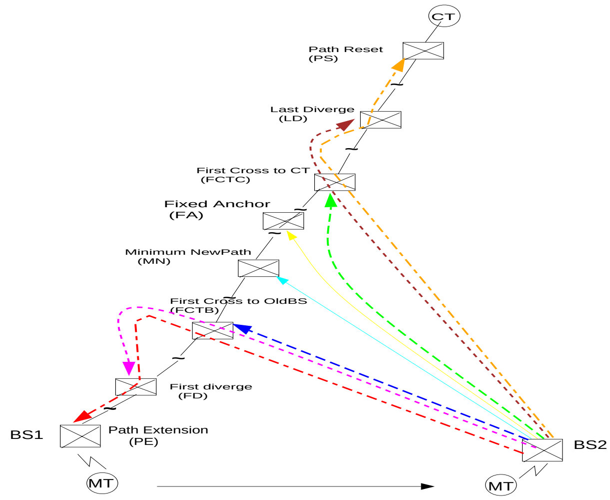

Figure 3: Crossover Switch (COS) in handoff control

accepted in current ATM Forum meeting that a GCID should be introduced for identifying a connection through a path other than its original path, which is useful for (1) connection path loop removal and (2) connection path re-routing.

On the other hand, the OldPath COS Discovery does not need a GCID since the COS discovery signaling is along with the original connection path so the connection can be identified by local ID hop-by-hop.

We have classified handoff control protocols by the methods of handoff initiation, path re-routing algorithms and methods of COS discovery. Figure 4 shows the possible combinations. For example, a protocol can use NewBS Initiation, NewPath COS Discovery and Last Divergence COS. It is shown that the OldBS COS Discovery can only be combined with the OldBS Initiation and few types of COSs.

3 Signaling mechanisms for handoff control

Given the possible alternatives in handoff control protocol design, we expect a generic mechanism which can adapt to the variations of the access network

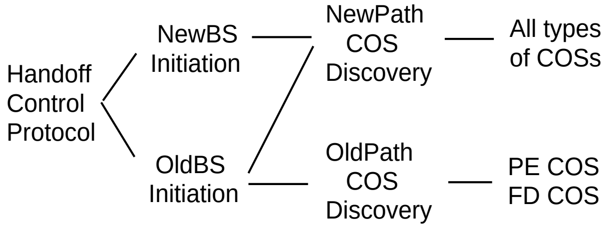

Figure 4: Classification of handoff control protocols

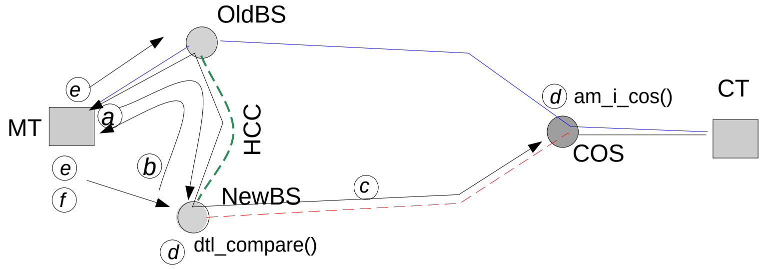

Figure 5: Handoff control process

and performance criteria. The signaling mechanism we propose in this section is flexible enough to meet the expectation.

3.1 Control procedure

Inspired by software architecture design for our mobile ATM prototype, we have found that the handoff control process becomes simple and consistent if only the NewPath COS Discovery is used. In this case, the starting point of the NewPath is always fixed at the NewBS. Then a single signaling syntax and sequence can be defined for all types of path re-routing algorithms (COS types).

The handoff control process based on NewPath COS Discovery shown in Figure 5 has following steps: (a) A mobile terminal (MT) sends an initial request to the NewBS, asking for registration resources on the NewBS, including a new ATM address, radio frequency and signaling channels. The request goes directly to the NewBS or indirectly from the OldBS to the NewBS through a wire line handoff control channel (HCC), for OldBS initiation or NewBS initiation, respectively. (b) A response to the initial request is answered, with the registration success or failure, directly or indirectly from the NewBS to the MT. (c) After the resources is registered on the NewBS, the handoff process for data VCs starts via ATM signaling. (d) COS discovery is performed along with the NewPath setup for each data VC. A am_i_cos() function is used for finding a COS switch with certain condition checks. (e) The MT leaves the area of the OldBS and enters the area of the NewBS after all data VCs have been handed off. It sends a informing message to OldBS and NewBS to release old control resources and activate new resources. (f) Finally, the MT activates each data VC to the NewBS, either one by one or as an atomic action.

3.2 Signaling syntax and sequence

Based on the control process in Figure 5, we define a signaling syntax by extending mobile signaling and ATM signaling specifications. As an example, in

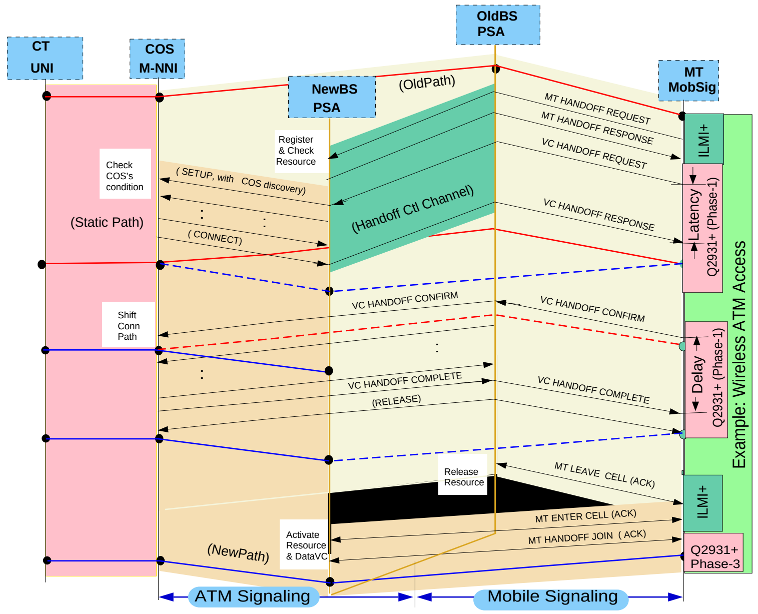

Figure 6: Signaling sequence of handoff control messages

wireless ATM case, the extensions are made for ATM signaling at UNI and NNI interfaces, which includes new and modified ILMI (Interim Local Management Interface) and Q2931 signaling messages. In Figure 6, we represents the extension sets as ILMI+ and Q2931+, respectively. New messages and modified messages are shown in time sequence. The signaling sequence can be explained from the following aspects.

Resource registration on NewBS

Through ILMI+ signaling, a mobile ATM terminal registers on the NewBS to obtain resources, such as ATM address, signaling PVCs, radio frequency. The mobile may not need a full registration to the NewBS as it boots up, but the resources availability must be checked before data connections' handoff. The ILMI+ messages MT_HANDOFF_REQUEST /RESPONSE are used for resource acquiring from NewBS, MT_LEAVE_CELL releases the resources on OldBS and MT_ENTER_CELL activates the using of the resources on NewBS.

Data VCs' path re-routing

Data VCs' path re-routing is carried on by Q2931+. There are three phases as shown in Figure 6. In the first phase, the VC_HANDOFF_REQUEST /RESPONSE are used which initiate data VC's path re-routing. The existing ATM UNI/NNI messages SETUP/CONNECT with new information elements (IEs) are used for NewPath establishment and COS discovery. A GCID IE is used for NewPath COS discovery which identifies a connection from a path different from the original path. A HCIE (handoff control) is used in SETUP/CONNECT/RELEASE to indicate that these messages is used for handoff control process and it can carry the algorithm related information, such as COS type.

COS discovery

In Table 1, we list destination addresses and COS detection functions am_i_cos() for the re-routing process using all different COS types. The destination address in SETUP message and am_i_cos() function to be used on switches are determined according to the HCIE in the VC_HANDOFF_REQUEST message.

COS	**Destination Address**	**am_i_cos()**
Path Extension (PE)	OldBS	dummy
First Divergence (FD)	OldBS	check routes of Connections /w GCID
First Cross to OldBS(FCBS)	OldBS	check GCID
Min. NewPath (MNP)	multiple switches on OldPath	check GCID compare dists
Fixed Anchor (FA)	a fixed ATM switch	dummy
First Cross to CT(FCCT)	CT	check GCID
Last Divergence (LD)	CT	check routes of Connections /w GCID
Path Reset (PRST)	CT	dummy

Table 1: **Destination Address and am_i_cos() Function for COS discovery**

Based on PNNI routing information, it is possible to avoid checking am_i_cos() function on every switch the VC HANDOFF REQUEST traverses. We will not discuss it because of the paper's space limitation.

Optional phases for VC path re-routing

Only the phase 1 performed by VC_HANDOFF_REQUEST/RESPONSE is mandatory for data VC path re-routing. However, shown as in Figure 6, two additional phases are used for reducing cell loss. The second phase, performed by two new messages – VC_HANDOFF_CONFIRM /COMPLETE, is used for shifting connection path from the OldPath to the NewPath. With this phase, the data transmission can be continued while the NewPath is established. The third phase, performed by new messages – MT_HANDOFF_JOIN (ACK), is used for assuring the completion of the connection path before data transmission starts. If data loss is not an issue at the cell level, the second and the third phase can be omitted.

Handoff delay and latency

In a three phase data VC handoff procedure, we define the period of the first phase as *Handoff Latency*. The handoff latency delays the whole handoff process so that a mobile user may risk losing the connection if the latency is large. The period of the second phase is defined as the *Handoff Delay*, in which there is a potential of cell loss. These performance values are very important factors in chosing path re-routing algorithms.

4 Implementation and Experiments

4.1 Software Architecture

Mobile ATM protocol stacks on mobile terminals, base stations and ATM switches are shown in Figure 7. The mobile terminal runs a mobile signaling module (MObSig) which can be either WATM UNI or nonATM signaling. Mobile signaling messages are interpreted by the proxy signaling agent (PSA) on basestation and converted to ATM signaling messages. Data packets are converted to ATM cells on basestation and each connection has a route which bridges wireless device and ATM device. An enhanced NNI ATM signaling controller (M-NNI) is running on ATM switches, which checks COS in a path re-routing procedure.

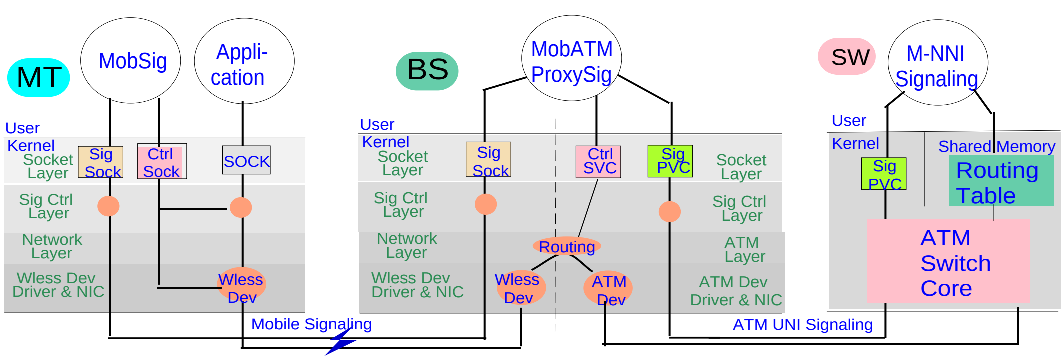

Figure 7: Protocol stack of mobile ATM networks

4.2 Prototype System

We have implement a proof-of-concept prototype system (Mobile ATM Version 1.5). The prototype currently supports handoff through NewBS initiation, NewPath COS discovery and *First-Cross-to-CT* path re-routing algorithm.

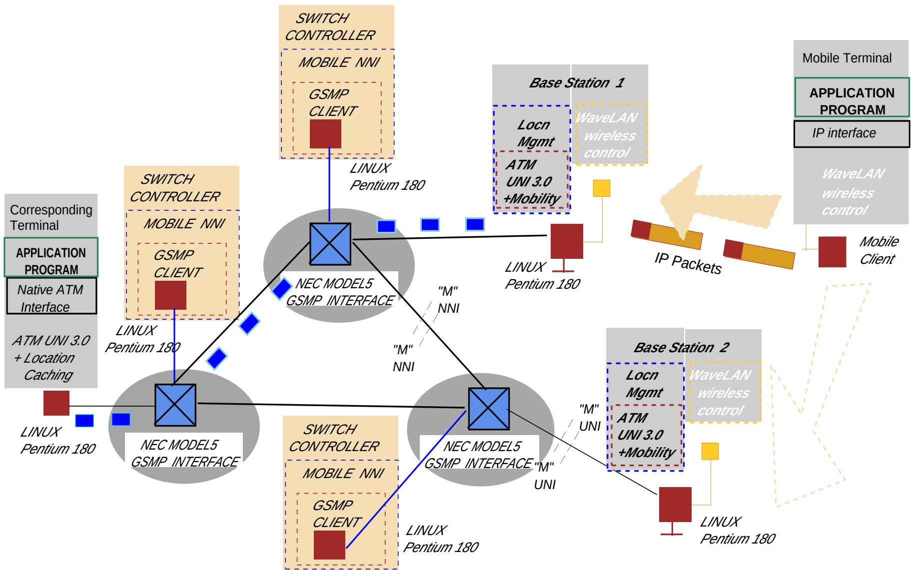

Figure 8: Mobile ATM network demo system

The system is shown in Figure 8. It uses WaveLAN as wireless access. At base stations, the IP packets from the WaveLAN is converted to ATM cells. And the first IP packet for an IP connection will trigger ATM signaling for ATM connection setting up in the PSAs on base stations. When mobile terminal has a handoff by changing its default gateway from one base station to another, a new connection setup is triggered on the new base station (NewBS. As the SETUP message cross the COS which has the original connection with the same GCID, a CONNECT message is sent back to the NewBS. Then a new path is set between the NewBS and the COS. Location management is also supported in the system.

A new prototype Mobile ATM Version 2.0, which intends to support end-to-end wireless ATM, is currently being designed based on the software architecture given in Figure 7.

4.3 Experiments in prototype system

The performance of path re-routing algorithms were not compared through experiment in this setup (v1.5). Instead, we compared the signaling delays for setting up a new call (Initial Delay) and re-routing a handoff call (Handoff Delay). In our prototype system, a new call is always between MT and CT and path re-routing is always at the same switch. We measured the delay at base station's UNI signaling mobile. The results are: (1) Initial Delay is around 18 msec and (2) Handoff Delay is about 5 to 6 msec. We can see that although COS is the last switch on the connection path, Handoff Delay is much smaller because the Initial Delay includes the delay of the application on CT.

5 Conculsions

A handoff control protocol is designed to use alternative path re-routing algorithms according to network performance criteria. Various handoff control strategies can be supported through one signaling syntax within a single software architecture. We have conducted the performance analysis on comparing alternative path re-routing algorithms within this framework, which will be published in separate paper. The complete version of the paper will give a more detailed protocol design including signaling state diagrams.

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