Ring Based Reliable IP Micro Mobility Network

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Abstract

The emerging IP technology requires that the Internet and IP backbones of 3rd and 4th generation mobile systems can be reached via IP based micro mobility access networks. There are already several micro mobility protocol recommendations. Almost all of them are based upon a tree topology network of routers. In this paper we give a survey about other possible topologies and a new ring-based access network topology is introduced and analysed, which can be used as a reliable micro mobility network.

1. Introduction

Internet and telecommunications seem to converge nowadays. The resulted so-called 'infocom' network of this convergence will probably be based on IP. As the circumstances and requirements were different at the time of the design of IPv4, the new version of the protocol, IPv6 will have several improvements and additions. One of the requirements that are hard and difficult to fulfil using IPv4 is the support of mobility. However, Mobile IP will be an integral part of IPv6.

Because Mobile IP [1] requires a lot of communication between the mobile node and its home agent, it provides a large-scale but slow mobility. Below this Mobile IP mobility a small-scale but fast mobility protocol is needed. This small-scale mobility is often called micro mobility, referring to Mobile IP as macro mobility.

The IETF workgroup Context and Micro-mobility Routing "Seamoby" [5] was formed at the end of 2000, and has no RFCs and only 3 drafts. Although this is a new research field there are already several recommendations for micro mobility protocols, for example Cellular IP [2] or HAWAII [3].

Most of these micro mobility protocols are based upon a tree topology network. In this paper we give a sophisticated alternative to this tree topology.

This paper is organised as follows: In Section 2 the classical micro mobility network architecture is described, and possible topology alternatives are examined. Section 3 describes in detail how a *ring* topology network can be used in a micro mobility domain. Section 4 presents our new solution called *hierarchy of rings*. Then in Section 5 we compare the "classical" tree topology with the presented topologies.

2. The Alternatives

2.5G systems (GPRS) use an IP backbone and a special protocol for the access networks. 3rd and 4th generation mobile systems are based on an IPv6 backbone, and IP should be used as far as to the user terminals.

Our micro mobility network should be connected to the Internet or to some other IP based network.

2.1. Classical Micro Mobility Network Architecture – The Basic Model

A micro mobility network is connected to the Internet via gateways. As probably wireless access is used, the service access points (SAP) will be called base stations (BS). The traffic shape of a micro mobility network is characteristic. Most of the traffic flows between a gateway and a SAP, and downlink traffic (that is sent form a gateway to a SAP) is usually much more than uplink traffic. (MNs get long answers to short questions, e.g. Web browsing).

As MNs are wandering around within the micro mobility network, dynamic routing is needed. This makes routing an important question of a micro mobility network. The actual positions of the MNs have to be stored in a (possibly shared) database.

Most micro mobility protocols define one gateway, and a tree topology network with the gateway as the root. All the traffic of the whole micro mobility domain flows through the gateway.

Every node has one uplink neighbour (parent) and may have some downlink neighbours (children). The nodes that do not have any children are called leaves. The leaves are the base stations in the micro mobility network, the nodes with children are the routers. Fig. 1 shows the general architecture of a tree topology micro mobility network. As we go higher and higher in the tree, more and more link capacity is needed.

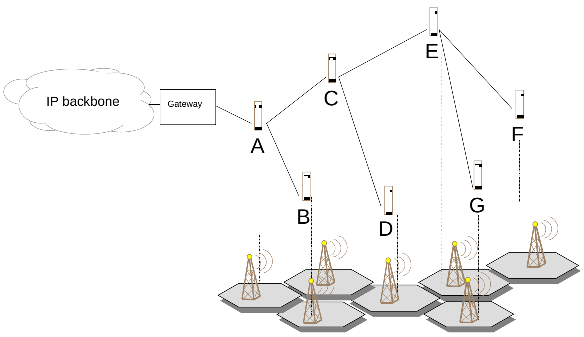

Figure 1. A tree topology micro mobility network

Each of the routers maintains a database where information is stored about the locations of the MNs that are in the subtree under the router. [4]

2.2. Aspects

Let us summarise the most important aspects of micro mobility network topology examination:

- reliability, vulnerability,
- scalability,
- connection to IP backbone
- wandering MN, complexity of routing,
- special traffic shape.

In our model, links and nodes have two states: working/broken, they are random variables, and are independent (at least until the occurrence of the first error). If the error probability is fairly low, the performance of a system that tolerates one error is much better, than the performance of a system that cannot tolerate any errors.

2.3. Quantitative Survey of Alternative Topologies

Here we summarise the most commonly used network topologies from a micro mobility point of view [6].

The *tree* is the "classical" micro mobility network topology. Both Cellular IP and HAWAII use tree topology networks. Most of the requirements are met, the major weakness is vulnerability.

A *bus* topology network can be connected to the Internet via gateways. If multiple gateways are used, the reliability could be satisfactory. There are no routing problems, an access protocol is used instead (ALOHA, CSMA). The serious problem with the bus is its inscalability. If it is used in a micro mobility network, the size is strongly limited.

The *star* is a centralised network topology. All the nodes are connected to the central node. The central node can be used as a gateway, but it is expensive, other nodes are simple, thus cheap. Routing at the central node is not very complex, and there is no routing at all at other nodes. This network topology really suits the traffic shape of a micro mobility network, where most of the traffic flows between the gateway and base stations. Unfortunately vulnerability is one of its weaknesses, as a central node breakdown is critical. This is one of the reasons why a double star is often used. In a double star, the central node is duplicated, and they are connected to each other. Packets then can be sent to both gateways. Another weakness is inscalability. As the number of base stations increases, routing at the central node becomes resource consuming.

In a *ring* there are exactly two paths between two nodes. If a link or node breaks down, there is still one path left, so it is much more robust than the tree. In a micro mobility ring multiple gateways should be used of course. Routing in a ring is simple. However, the ring does not expressly suit the traffic requirements, and inscalability is another problem. As the number of BSs increases, routing does not get more complex, but links may become overloaded.

A *full mesh* is nonsense of course, because it is extremely inscalable, and does not suit the traffic shape anyway. A *partial mesh* can be scalable, and multiple gateways can be used. It is robust, if there are several paths between any two nodes, and there are multiple gateways. The only problem is that routing becomes difficult. The packets have to be routed correctly even when some of the links are broken. So a complex routing protocol has to be used, and all of the nodes have to function as routers, so unless very sophisticated routing is used, it is an inefficient and expensive solution.

2.4. Preferable Topologies

The mesh looks quite attractive, but when designing a routing protocol for meshes, a lot of things should be reinvented, and the result would probably be an extremely complex protocol.

The double star and the ring seem to be the two topologies that suit the requirements beside the tree. In the next two sections the ring topology is examined in detail concentrating on the micro mobility aspects and a new reliable micro mobility network topology will be introduced based on the results.

3. Ring

The ring consists of several nodes and two-directional links. This is of course not an autonomous system, but an IP micro mobility domain, so it is connected to the Internet (or IP backbone) by a router or possibly routers.

In the following subsections we present how a micro mobility domain can be based upon ring network topology. Of course there might be some other micro mobility architectures over a ring than the one described here, however our solution improves not only the reliability of the system but the routing capabilities too.

3.1. Ring Self-restoration

In a ring each of the nodes are connected to exactly two other nodes, to its neighbours. Having a two-directional ring, a packet from one node to another can be sent two ways. If a link breaks down, the ring does not break up to pieces, as a tree would do. Any node can still send packets to any other node, there is still one path left. It is not trivial how a node can know which direction it can reach a destination, but in the case of one link failure communication is always possible between any two nodes.

What happens when there is a node failure? It is equivalent to the case when the two links of that node break down. Still any two nodes can communicate except the broken-down one of course.

How should a node know which direction to send the packets? A notification of the breakdown can be advertised throughout the network, but it is not too efficient, and requires some computation at each node, which makes them more expensive. It is most desirable to solve this problem at a level as low as possible. The answer is the self-healing ring. This self-healing ring is like the MSSP (Multiplex Section Shared Protection) ring in the SDH world.

In a self-healing ring only one half of the capacity is used as operational capacity, the other half is reserved for critical situations. If a link breaks down, the two neighbouring nodes realise the breakdown, and the spared capacity of all other links is used to replace the broken link, see Fig. 2.

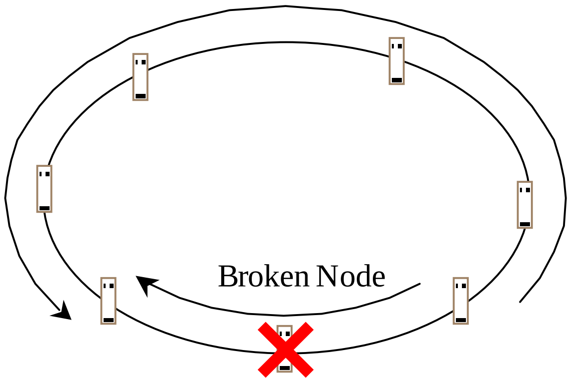

Figure 2. The self healing ring

Thus, by means of a self-healing ring, link failure correction can be performed below the micro-mobility level, and a reliable communication network is provided to the micro mobility protocol. In the remaining part of this paper the self-healing ring will be treated as a reliable ring from the micro mobility point of view.

3.2. Multiple Gateways, Multiple Connections

The reliability of the ring is now satisfactory, but how should we connect the network to the IP backbone? Some of the nodes in the ring have to function as micro mobility gateways. At least one gateway is needed, but having only one might make the connection between the backbone and the access network too vulnerable. A gateway failure or a link failure at the gateway can separate the whole micro mobility network from the backbone. On the other hand having more than one gateways obviously makes the micro mobility protocol more complex. But as we will see, in ring network topology, it is easy to handle multiple gateways.

Besides increasing reliability, having more gateways has another advantage. If a gateway is closer to a node, a packet sent by the node can be routed out from the micro mobility network earlier (i.e. on a shorter path) and a received packet can reach the node earlier. Thus, having more gateways allows the link capacities to be better utilised.

3.3. Node Types

Now we summarise what kind of nodes should be used in a ring topology micro mobility network. The self-healing mechanism has to be implemented at each node. This is what the nodes have in common, but the functionality of the nodes can be different. At the micro mobility level, the node types are:

- gateway + router: The router routes the packets between the two neighbouring nodes and the gateway. The gateway sends packets out to the IP backbone and receives packets from there. There are probably about two or three nodes of this type in the access network.

- BS + router (SAP): The router routes packets between the two neighbours and the BS. The BS sends packets to the MNs and receives packets from them. This is probably the most common node.
- router + special function: There can be nodes that neither function as gateways nor as BSs, but have some other function such as packet authentication or traffic analysis.

Fig. 3 shows the architecture of a ring topology micro mobility network.

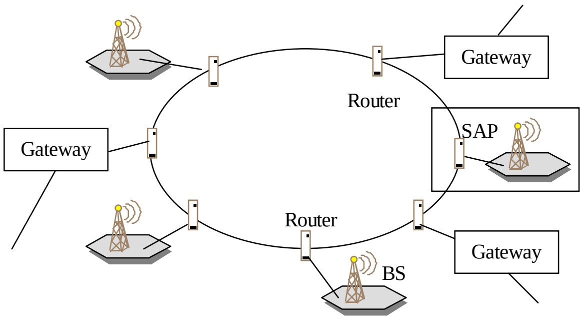

Figure 3. Ring topology micro mobility network

3.4. Uplink and Downlink Routing

Once we have a reliable network with reliable connections to the IP backbone we want our micro mobility protocol to work over this network. Micro mobility routing questions over a ring topology network are addressed in this subsection.

As already mentioned in Section 3 the architecture presented here is not the only solution, some even more powerful solutions may exist, but this one can illustrate how the features of a ring can be profited when building a micro mobility domain.

Most of the nodes of the ring are the service access points (SAP) of the micro mobility network. Some of the nodes are gateways to the Internet.

3.4.1 The Basic Structure

As it was mentioned in Section 2, most of the data flows between a BS and a gateway. The two directions of this kind of traffic will be handled separately. *Uplink* traffic means data originating from a SAP and being delivered to a gateway, *downlink* traffic means data flowing from a gateway to a SAP. Traffic between two SAPs will be called *internal* traffic. In a micro mobility environment the internal traffic is insignificant compared to uplink and downlink traffic, and uplink traffic is usually much less than downlink traffic (e.g. WEB browsing).

The basic idea is that we have a ring with two-directional links and use one direction for the traffic. The full capacity of the other direction is reserved for self-healing (see Subsection 3.1.). Thus we have a safe ring with one-directional links. This makes routing much more simple, because nodes on the ring do not have to decide which direction to send packets. On the other hand packet routes are not always optimal in the micro mobility network.

Routing in the micro mobility domain is based on some kind of ID of the MNs. This ID can be the IP address or the care-of-address of the MN or some other ID that identifies the MNs uniquely.

3.4.2 Service Access Points

The SAP consists of one BS and one router. The function of the BS is independent of the network topology, a BS in a ring topology network operates the same way as a BS of a tree topology network. Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), Code Division Multiple Access (CDMA) or a combination of these can be used to access the common medium.

In our model the router of the SAP has to maintain a database about the MNs that are connected to that SAP. A SAP does not have to have any information about other MNs, BSs or gateways, it just has to know which MNs are connected to it. These database entries are soft state, which means that if the MN leaves without notification, they are torn down after a time.

3.4.3 Downlink Traffic

IP routing at the Internet is beyond the scope of this paper. Micro mobility downlink routing begins when one of the gateways receives a packet from the Internet. The packet can be originated from a Mobile IP HA (Home Agent) or a CN (Corresponding Node) somewhere on the Internet. The packet is passed to the router, and as we have a one directional ring, the packet is launched onto the ring.

All the nodes except the SAP that can find the recipient MN in its database forward the packet. If the router of a SAP identifies the destination address as an address of an MN connected to that SAP, it passes the packet to the BS instead of forwarding it. If the recipient is in none of the databases, the packet travels around the ring, and the gateway that sent it off receives it again. From receiving it, it can know that the MN cannot be found in this network, and can act accordingly.

3.4.4 Uplink Traffic

If the BS of a SAP receives a packet from a MN, it passes it to the router. The router launches it on the ring. All the nodes forward the packet on the ring until it reaches the first gateway. As the gateway router recognises that it is an uplink packet, instead of forwarding it along the ring it passes it to the gateway. If a router of a SAP receives a packet that it has sent out, it can know that the packet has travelled around the ring. It can deduce that probably there were more than one link or node errors in the ring, the ring has fallen apart, and there is no gateway in that part.

It is of course possible to allow the BS to specify which gateway it wants to use for sending out the packet to the backbone instead of the first one the packet reaches.

3.5. Registration

When the MN enters the micro mobility network or it is switched on there, it has to register both to its Mobile IP home agent, and to the micro mobility network. Mobile IP registration is beyond the scope of this paper.

The micro mobility registration is very simple. Unlike in the case of a tree topology network, the position of the MN has to be stored only at the SAP where it accesses the network. When the BS sends a registration message to the router, the router adds a new record to the database. Later when it receives a packet sent to the MN, it will pass it to the appropriate BS.

Because database entries are soft state, the MN has to send registration update messages from time to time to prevent the entries from timing out, like in Cellular IP [2]. These registration update messages are almost the same as the registration messages. When receiving a registration update message, the router resets a timer instead of adding a new entry to the database.

3.6. Handover

In a micro mobility environment handover is initiated by the MN. The BS which it moves away from is called the *old BS*, the BS it moves to is referred to as the *new BS*. We consider soft handovers because all the members of the 3rd generation IMT2000 family use wideband CDMA. Therefore the MN is able to communicate with more than one BSs at the same time.

When soft handover is used, the MN informs the new BS that it wants to access the network there. It is similar to a registration at the new SAP. The router of the new SAP adds a new record to the database. From that time the router passes packets to the BS and does not forward them. Then the MN informs the old BS about its leaving. The old SAP's router sets up a timer for the database entry, and when the timer expires, it deletes the entry. This timer is needed to avoid the loss of the packets that were already on the way between the old and the new BSs when the new BS was notified. There is a fixed amount of time between the addition of the new entry at the new SAP's router and the deletion of the old entry at the old SAP's router. During that time the MN can send packets to both BSs. Depending on the order of the old and the new BSs in the ring, during the time of the handover, packets may arrive only from the old BS or from both the old and the new ones This is a soft handover type called *simple* handover.

There is another handover mechanism that can be used in a ring topology micro mobility network, called *advertised* handover. The advertised handover has a soft and a hard variation. MNs that are unable to maintain connections to more than one BSs can also use the advertised handover. The disadvantage is that it requires communication on the ring, and hence it is slower than the simple handover. In the advertised handover it is not the MN but the new SAP that notifies the old SAP about the handover. As the new BS receives an advertised handover message, it passes it to the router. The router launches the message on the ring, where it travels to the old BS. The old BS deletes the database entry when it receives this message. In the hard variation, the MN is only connected to the new BS, thus packets sent by the old BS are lost.

3.7. Standby Mode, Paging

MNs that are not transmitting or receiving any data may switch to "idle" state to prolong battery life. When the MN is in idle state, it does not have to notify the network about each handover, hence the network does not know its exact location. In order to locate the MN in case of an incoming call, Paging Areas (PAs) are defined, and the MN has to notify the network only when it moves from one paging area to another. In case of a ring topology network, the whole ring can be one paging area.

When the MN switches to idle state, it sends a control message to the BS. The BS router sends the message around the whole ring, and all the routers put the ID of the MN in their database as an idle state MN. These entries have to be refreshed, because they are also soft state, but they timeout period is much longer than that of the routing entries.

When a packet destined to an idle state MN arrives to the network, it travels around the ring, and all the BSs send a paging message to the MN, and delete the paging entry from the database. When the MN receives the paging message, it has to switch to active state, and register to the micro mobility network. At registration, the appropriate SAP adds a routing entry to its database, and packets can be sent to the MN.

3.8. Further Considerations

3.8.1 Breakdown Considerations

If a BS breaks down in the ring, the ring heals itself, and both uplink and downlink traffic routes remain the same. What happens when a gateway breaks down? The ring heals itself and the new network topology will be a ring without the broken down gateway node. Fig. 4 shows how the uplink traffic that the broken gateway used to send out to the Internet is sent out by the next gateway in the ring.

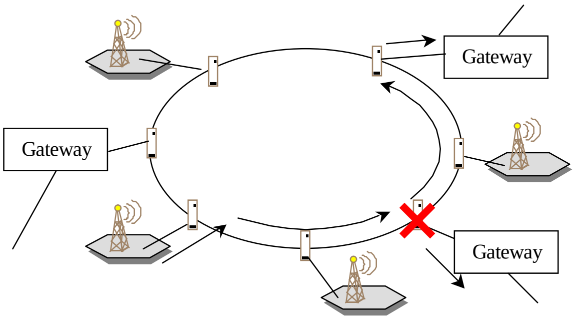

Figure 4. Broken gateway in a ring topology micro mobility network

3.8.2 Gateways with Enhanced Databases

In a micro mobility network there are a lot more BSs than gateways. Using more complex gateways with huge databases does not significantly raise the costs. To build a cost effective network the SAPs should be as simple and cheap as possible. It might be a good idea to store some more data at the gateways. In Section 4 we will see that it is useful to have a list of the MNs staying in the network at each of the gateways. If we would like to maintain these lists in the gateways, the registration has to be more complex. When the MN registers at the SAP, after updating the database a message has to be sent around the ring informing all the gateways about the new MN in the network.

It is also possible to store the ID of the idle state MNs at the gateways instead of the routers. When a packet arrives to the idle state MN, a paging message is sent around the ring by the gateway. This paging message makes the MN switch to active state.

3.8.3 Network Size

It is hard to estimate the size of the micro mobility domain that a ring topology network can serve. We can have probably a few hundred SAPs and a few (not more than ten) gateways.

Serving 50 MNs should not be too much for a SAP, so the range of a ring topology micro mobility network can be a building for example.

In order to extend the size of the network multiple ring topology networks can be used, and when the MN moves from one network to another a macro mobility (Mobile IP) handover takes place. In the next section we present, how to build large size scalable network from the above introduced basic ring topology, where these Mobile IP handovers can be avoided.

4. Scalable Hierarchy of Rings

The most serious weakness of the ring is that it does not scale with size. To solve this problem we recommend a hierarchical interconnection of ring topology networks.

4.1. The Topology

In a tree topology micro-mobility network every node has a parent node (except for the root), and every node may have some child nodes under it. A hierarchy of rings is similar to this topology. It is a tree with rings instead of the nodes. Every ring has a parent ring (except for the root ring), and every ring may have some child rings under it. In our network there is exactly one root ring, and all the rings are self-healing rings like described in Subsection 3.1.

By using this topology the advantages of the tree and the ring topology can be combined.

All the rings are self-healing rings, so one error in a ring is corrected below the IP level. To build a robust network that can handle failure of the interconnection links that connect the rings of the access network, every ring should have multiple connections to its parent ring.

4.2. Node Types

In a hierarchy-of-rings topology micro mobility network there are more node types than in the basic ring topology. These are the following:

- gateway + router: This is the same type of node that we had in a single ring network. Our hierarchical network has gateways only in the root ring.
- BS + router (SAP): This is the same as what we had.
- Interconnection node: these nodes connect the parent ring with a child. There can be two functions separated in an interconnection node. It acts as a base-station-like router in the parent network, and acts as a gateway-like-router in the child network. These two functions can even be separated physically.
- router + special function: The hierarchy can have special nodes too.

- combined: The hierarchy can have combination of the above listed node types too.

4.3. Ring Types

In our micro mobility network a ring has either BS routers or child rings, but not both. Actually both of them can be allowed, but this restriction makes the network much more structured. So there are two types of rings: *access rings* (with BSs but no children) and *transport rings* (with children but no BSs).

Access rings are actually ring topology micro mobility networks with enhanced database gateways like the one described in Subsection 3.8.2., but with a bit more functionality. The interconnection nodes that connect the access ring to its parent act like the gateways in the simple ring structure. As they are extended database gateways they have information about all the MNs connected to this access ring. Fig. 5 shows a micro mobility network with this topology. This network has three access rings, two transport rings and the root ring has two gateways.

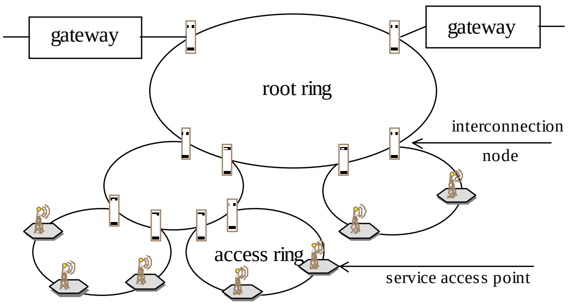

Figure 5. Hierarchy of rings topology micro mobility network

A transport ring is also similar to a ring topology micro mobility network. The interconnection nodes that connect the ring to its parent act like gateways, the interconnection nodes that connect the ring to its children act like the SAPs. They have information about all the MNs that are directly or indirectly connected to the child ring.

Thus all the interconnection nodes have a database of all the MNs that are connected to the micro mobility network "under" them.

4.4. Uplink and Downlink Routing

4.4.1 Uplink Traffic

MNs send packets to a BS of an access ring over the air interface. The BS passes them to the BS router. The router launches them on the ring, and they travel along the ring until they reach an interconnection node. As the interconnection node identifies these packet as uplink packets, it passes them "up", thus launches them on the parent ring instead of forwarding them. Packets are passed up ring by ring to the root ring by the interconnection nodes. From the root ring the first gateway sends them out to the IP backbone.

4.4.2 Downlink Traffic

When a packet arrives from the Internet, a gateway router launches it on the root ring. As all the interconnection nodes know which MNs are connected under them, the first interconnection node that has the recipient address in its database launches the packet on the child ring instead of passing it on. The packet travels down from transport ring to transport ring until it reaches the proper access ring, where the appropriate BS passes it to the MN.

It is easy to route packets correctly if all the interconnection nodes have the information about the MNs under them. It will be elaborated how these databases can be maintained.

4.5. Registration

Now let us present what happens when a MN registers to the micro mobility network and how the databases should be built up. The micro mobility registration message travels from the access ring where the MN registers, up to the root ring and all the databases are set up. The registration message travels around the whole access ring, the whole transport rings, and the whole root ring, so all the interconnection nodes and gateways can set up their databases correctly. Registration messages can be passed up by all the interconnection nodes or just the first one it reaches. If they are passed up by all of them, multiple registration messages have to be handled in the parent ring. If only the first interconnection node passes them up, then the message has to be altered by the first interconnection node so that other interconnection nodes can know that it has already been passed up.

4.6. Handover

If the MN cannot be connected to more than one base station at a time a Cellular IP-like [2] hard handover mechanism can be used. Here soft handover is explained in detail.

Consider the two paths: the one to the old BS and the one to the new BS. Going uplink the first ring that is part of both paths is called the crossover ring. The soft handover is similar to a registration. A control message travels up to the crossover ring. There the interconnection nodes that connect the crossover ring to its parent know that the MN is under them, they do not change the entries in their databases. A registration update message can be sent up to the root ring to prevent database entries from timing out. The interconnection nodes that connect the crossover ring to its child ring that is on the path towards the old

SAP delete the database entries, so they do not route the packets down any more. A release signal may be sent down to the old BS that tears down the database entries, but they will time out anyway. During the time of the handover the MN may send packets to both BSs, and packets may arrive from both BSs. If a release signal is sent down, it can be passed to the MN, so the MN knows that it will not receive any more packets from the old BS.

4.7. Standby Mode, Paging

It is obvious to define the paging areas as the access rings. When an MN switches to idle state, a message is sent around the ring, all the BS routers delete the MN from their database, and all the interconnection nodes put a paging entry in theirs. To prevent the database entries from timing out at higher levels, the interconnection nodes have to send route update messages up to the root ring while the MN stays in idle state.

When a packet arrives to the MN, it is routed down to the appropriate access ring, where the interconnection node sends a paging message around which makes the MN register at one of the SAPs and it switches to active state.

When the MN moves from one access ring to another in idle state, it has to notify the network. This case is very similar to a handover in active state. The MN sends an idle registration message to the new BS in the new access ring. This idle registration message travels around the new access ring. All the interconnection nodes put the paging entry in their databases, and from this point exactly the same procedure happens as in case of normal active state handover. The message travels up to the crossover router, and the path to the old access ring may be cleared explicitly or they can just left to be timed out.

5. Comparison of Tree and the New Solutions

The "classical" topology of a micro mobility domain is a tree. The two alternatives presented in this paper are the single ring and the hierarchy of rings.

Both of the new topologies provide better reliability than the tree. Both of them can tolerate at least one node or link error, while the tree is very vulnerable.

Routing in the ring is much more simple than in the tree. In the hierarchy of rings routing is more complex than in the tree, but not significantly.

A lot of the solutions of Cellular IP and HAWAII can be used in both the ring and the hierarchy.

The scalability of the hierarchy of rings is as good as that of the tree, the single ring is weaker in scalability.

The tree and the hierarchy of rings have to be connected to the Internet at the root or the root ring, while a single ring can have connections anywhere.

An advantage of the ring is that uplink and downlink traffic use the same links, so we do not have to decide beforehand how much capacity to allocate for uplink and downlink traffic.

In the ring and the hierarchy of rings the handling of idle state MNs is much more "local", than in a tree. In a hierarchy of rings, only one access ring has to know about an idle state MN.

Security questions were not considered in this paper, although it is one of the most important parts of micro mobility. Authentication is a crucial point. Similar security considerations are needed in all the three network topologies.

Conclusions

Alternatives of classical tree topology were discussed in this paper. We emphasised the usability of simple ring topology and the hierarchy-of-rings topology. We have shown that these proposed solutions have same routing capabilities as the tree topology, however their reliability is much stronger.

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