RELIABILITY CONSIDERATIONS OF IP MICRO MOBILITY NETWORKS

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Abstract

Mobile IP is the standard Internet mobility protocol. It is appropriate for global large-scale mobility but it proves to be slow in cellular mobility environment. Therefore new micro mobility protocols are needed. In order to solve the routing problems easily most of the micro mobility protocols use tree based network topology. However, a serious problem of this kind of topologies is its weakness in reliability. In this paper this problem and possible solutions are examined. The solutions we recommend here increase the reliability of a tree network topology without having degradations in the routing capabilities.

Keywords: Access Networks, Micro Mobility, Hierarchy of Rings

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].

In this paper reliability questions of micro mobility networks will be considered. Of course major changes should be avoided, because the micro mobility protocols were designed for tree network topology.

From reliability point of view a graph model is introduced, where links are the edges, and hosts are the vertices. Links have two states: working/broken, they are stochastic variables, independent (at least until the occurrence of the first error), and 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 is not able to tolerate any errors.

This paper is organised as follows: In Section 2 we give a short survey about the general architecture of micro mobility networks. Section 3 analyses the reliability of the traditional tree topology. In Section 4 we present and investigate the alternative network topologies such as bus, star, ring, mesh. In Section 5 the proposed reliable solution for IP micro mobility topology is defined. In Section 6 the reliability considerations of the new topology are discussed.

We would like to emphasise that only reliability aspects of the new topology is investigated in this paper. The proof of equivalence in routing of the proposed topology and traditional tree topology is discussed in other papers, e.g. [9]

2. General Architecture of Micro Mobility Networks

IP micro mobility access networks are connected to the IP backbone via gateways. Because of the wireless access, service access points (SAP) are 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. Downlink traffic (that is sent form a gateway to a SAP) is usually much more than uplink traffic (mobile nodes (MNs) get long answers to short questions).

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. Every node has one uplink neighbour (parent towards the gateway) and may have some downlink neighbours (children towards the MN). In Fig. 1 D is a downlink neighbour of C and A is an uplink one respectively. The nodes that do not have any children are called leaves. The leaves are base stations in the micro mobility network, the nodes with children are routers.

The root node or gateway is connected to the IP backbone, and all the traffic of the mobile nodes flows through it. All the routers maintain a routing cache [4], where data is stored about the MNs that are in the subtree under the router. The routers know which child packets have to be passed to. As we go higher and higher in the tree, more and more link capacity is needed.

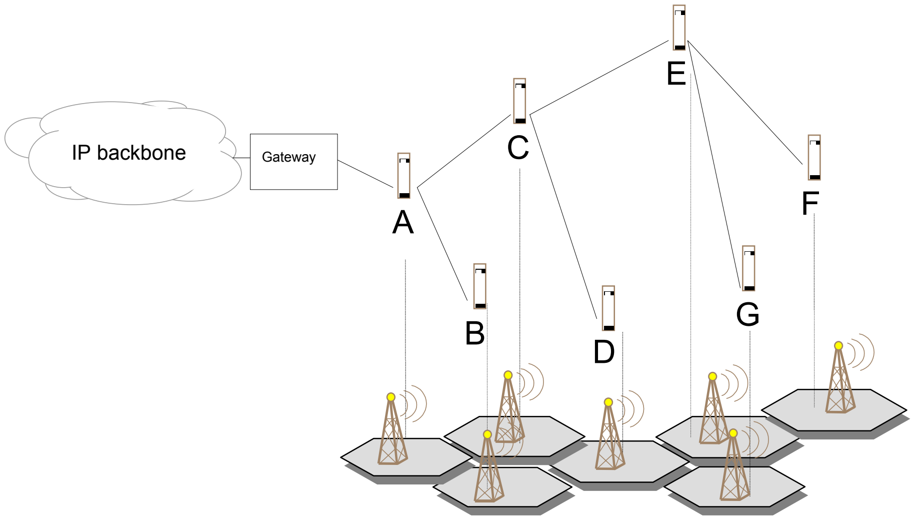

Figure 1. General architecture of micro mobility networks

3. On the Reliability of the Tree Topology

Tree topology means that there is exactly one path between any two nodes. So there is exactly one path between a base station and the gateway.

This is a rather vulnerable network architecture. Consider our graph-model, where links and nodes have two states: working/broken. If we suppose that all the traffic flows between a base station and the gateway, a link failure is equivalent to the failure of the node that is at the bottom of that link. The result is the same. A subtree is separated from the network.

It is even more severe, when the gateway router or the link between the gateway and the backbone breaks down. Then the whole micro mobility network is separated from the backbone, and no communication is possible between an MN in the network and another host on the Internet.

If this topology is so vulnerable, then why are almost all the micro mobility solutions based on a tree topology network? It is because the tree suits the routing requirements of the micro mobility network and signalling requirements of the micro mobility protocol very well. Both uplink and downlink routing are simple so simple and relatively cheap routers can be used. And at the same time the tree is a very scalable solution. The problem that we are concentrating on is the weak reliability of the tree.

There are two basic solutions for the reliability problem. One is to use a completely different network topology, the other is to try to make the tree topology more reliable somehow. If another topology is used in the micro mobility network instead of the tree, it has to be chosen carefully. There are several aspects. The network should be less vulnerable than the tree, of course, too complex routing or too complex signalling should be avoided, and scalability is very important for micro mobility networks.

If the tree topology is kept but improved, the aspects are similar. Links and nodes have to be duplicated and physically separated for safety reasons. This new network inherits a lot of the attributes of the tree, for example it probably suits the signalling requirements, and remains scalable. But routing and signalling becomes much more complex. The micro mobility protocol and the routing have to be redesigned.

4. Examination of Alternative Network Topologies

In this section, we investigate the possible various network topologies, which are suitable for micro-mobility networks. The special features of a micro-mobility network make some of the otherwise not that important aspects really crucial, and at the same time raise some new problems. The most important problems related to micro-mobility networks are:

- reliability, vulnerability,
- scalability,
- connection to other networks (Internet),
- wandering MN, complexity of routing,
- special traffic.

4.1. Tree

The tree is the "classical" micro mobility network topology. Both Cellular IP [2] and HAWAII [3] use tree network topology. Almost all requirements are met, the major weakness is vulnerability.

4.2. Broadcast Medium, Bus

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

4.3. Star

Star is a centralised network topology. All the nodes are connected to the central node. The central node can be used as a gateway to the Internet. All intelligence can be concentrated in the central node, other nodes are very simple, thus very cheap. Routing at the central node is not very complex, and there is no routing at the 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 a base station. Vulnerability is a weakness, 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 probably 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 time consuming.

4.4. Ring

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. 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 get overloaded.

An important ring type is the self-healing ring. In a self-healing ring only one half of the capacity is used, the other half is reserved for critical situations. It is like the MSSP (Multiplex Section Shared Protection) ring in an SDH environment. 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. Thus, one error can be corrected below the micro-mobility level, and a reliable communication network is provided for the micro mobility protocol.

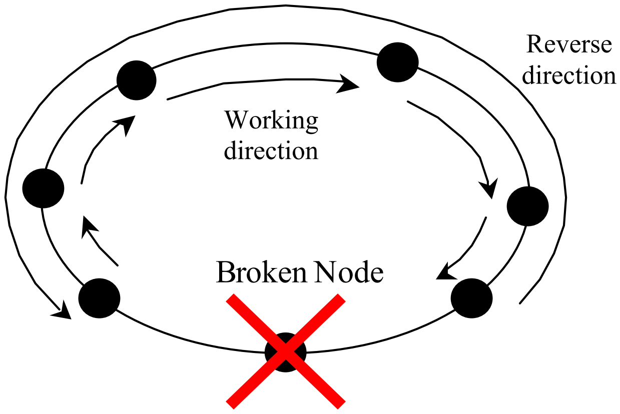

Figure 2. Self-healing ring with broken node

4.5. Mesh

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. 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 a very sophisticated routing is used, it is an inefficient and expensive solution.

5. The Proposed Reliable Solution for IP Micro Mobility Topology

To design an efficient and safe micro mobility network two methods, namely the new topology and the enhanced tree should be combined in some way. Our idea is to keep the tree topology and put networks instead of the routers and possibly instead of the base stations. Of course multiple connections should be used between the networks. This way we can increase the safety of the tree, while the routing and other signalling mechanisms (for example handover signalling) of the tree topology network can be used with minor changes. The two most powerful network topologies for this purpose seem to be the self-healing ring and the double star. In a tree the leaves and the intermediate nodes have different functionality, so it might be rational to use different topology networks in the leaves and instead of the routers.

We will not go into the details, the purpose of this paper is to show the basic idea how networks can be used instead of the nodes in a tree topology network. In our example network we use rings instead of the routers and also rings instead of the base stations, see Fig. 3. We call this topology *hierarchy of rings*.

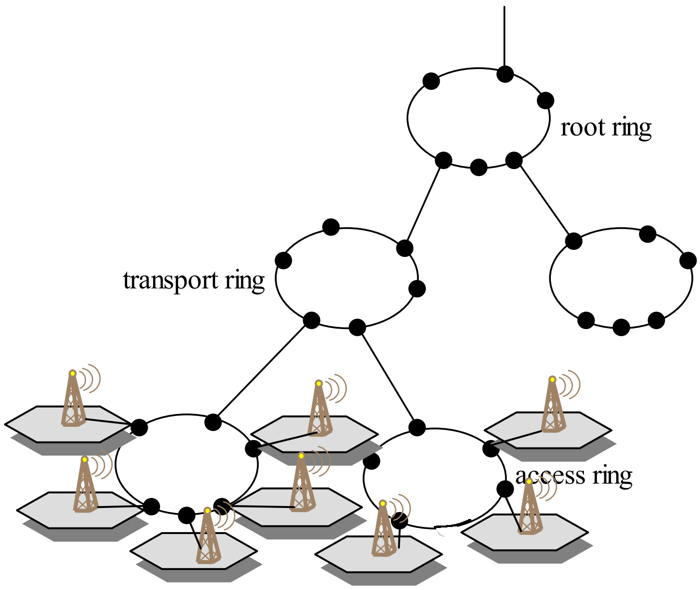

Figure 3. Hierarchy of rings network topology

All the applied rings are self-healing rings, so one error in a ring is corrected below the IP level. Every ring has a parent ring (except for the root ring), and every ring may have some child rings under it. To build a robust network that can handle failure of the links that connect the networks, every ring should have multiple connections to its parent ring, and the root ring should have multiple gateways. The multiple connections have to be also physically independent. Rings that are in the leaves of the tree will be called access rings, other rings are the transport rings. Let us see what type of nodes we have in the proposed topology:

- gateway + router: This type of node can be found only in the root ring. The router routes the packets between the two neighbouring nodes and the gateway. The gateway sends packets out to the Internet and receives packets from there.
- BS + router (SAP): We have nodes of this type only in the access rings. The router routes packets between the two neighbours and the BS. The BS sends packets to the MNs and receives packets from them.
- Uplink router: These nodes can be found in all the rings except in the root ring. They route packets between the two neighbouring nodes in the child ring and the parent ring. They functionality is similar to that of the gateway routers in the root ring.
- downlink router: These entities can be found in all the transport rings including the root ring. They route the packets between the two neighbouring nodes of the parent ring and a child ring. Note that uplink routers and downlink routers can always be found in pairs.
- router + special function: There can be nodes that neither function as gateways nor as BSs, and do not even do routing, but have some other functionality such as packet authentication, verification or traffic analysis.
- combined: A combined node for example is a node that works as a BS and as an uplink router at the same time. It is better to avoid these combined nodes and separate the functions.

Downlink routers and uplink routers are always in pairs, and the links that connect the rings run between them. These two routers with the link can be considered as one node of the network. They do not even have to be physically separated. This new node type is called an interconnection node. If the nodes of a tree are substituted with rings, and the links of a tree are substituted with interconnection nodes, the network does not look like a tree any more, see Fig. 4.

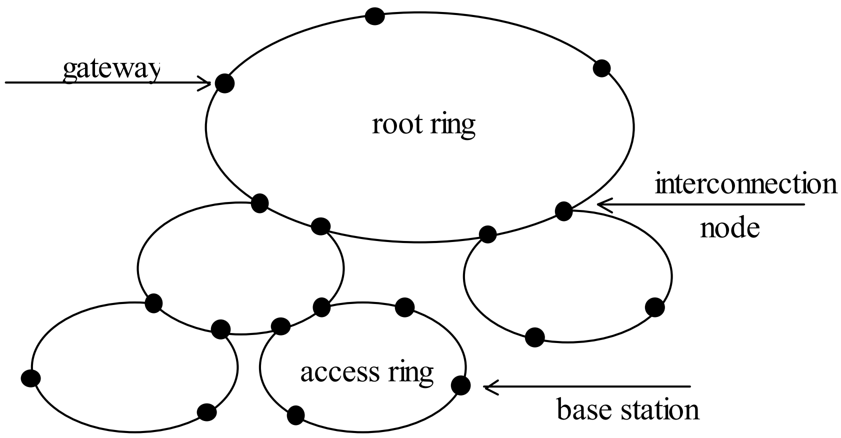

Figure 4. Hierarchy of rings network topology with interconnection nodes

6. Breakdown Considerations and Handling Topology Changes

In our two-state model a node breakdown is equivalent to a simultaneous breakdown of all the links of that node. Our proposed network can tolerate one node or link error. As a node breakdown is "worse" than a link breakdown, it is enough to examine node breakdowns.

If a SAP breaks down in an access ring, the ring heals itself, and the micro mobility protocol is not even affected. Some connections may be dropped, but the network continues to function normally.

An interconnection node breakdown means that both the uplink router and downlink router break down. This is apparently worse than just an uplink or downlink router failure. But as these two routers may be integrated, it is rational to suppose that they break down together. The ring from the interconnection node viewpoint towards the gateway is called the uplink ring, the ring towards the MN is the downlink ring. In this case both the uplink and the downlink ring heal themselves. The topology remains the same, only the number of interconnections is decreased by one. As there are more than one interconnections between any to neighbour rings, the two rings are still connected.

If a gateway breaks down, the number of gateways is decremented by one, but as we have more than one gateways, there is still at least one left.

Our hierarchy of rings topology can surely tolerate one node or link error, and if the error positions are not very unluckily distributed (for example all the gateways breaking down), it can probably tolerate even more.

The hierarchy of rings can be considered as a tree, where the functions in a node are separated. For example downlink routers maintain the databases of the MN positions, gateways connect the network to the Internet, but do not do any routing.

Topology changes caused by failures should be handled by the micro mobility protocol. Uplink packets should be passed up to the parent ring by the first uplink router they have reached. In case of an uplink router failure, another uplink router will pass the packets upwards. Downlink packets should be passed down to the child ring by the first adequate downlink router. A route update messages sets up the database entries while travelling up to the root ring from a BS. It should go around all the rings on its paths so that all the downlink routers will have information about the MN.

As topology modification is not too radical, we can use tree topology based protocols with minor changes. MN registration, handover, route update, uplink and downlink traffic, authentication, paging remains the same, but over a safer, enhanced tree.

Conclusions

In this paper the possibilities of building a robust micro mobility network were considered. We focused on alternative network topologies. The classical micro mobility network topology use the tree topology, here some other topologies were examined as well. The presented solution is the substitution of the nodes with simple networks in a tree topology network. After that a short overview was given how the various micro mobility specific problems can be handled in a network, where ring network topology is applied at the nodes of a tree. This way the scalability and simple routing of the tree and the robustness of a ring can be combined, and the result is a safe, scalable hierarchy of rings network topology.

Acknowledgments

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