Multiple Terminal Management in Mobile Ad Hoc Networks

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ABSTRACT

Ad Hoc networks have thus far been studied in small networks utilizing nodes with limited capabilities, in particular utilizing only one data link. However the possibility for more complex nodes with a multitude of interfaces exists. This paper proposes a sub-layer used to manage and take advantage of these interfaces and present them in a unified matter to the upper layers. The algorithm behind the protocol is being described and then implemented in the OPNET simulator. The results prove the correct functionality and adequate performance of the algorithm.

Keywords: MANET, directional links, MAC, handshake

1 INTRODUCTION

Ad Hoc networking promises to provide the next breakthrough in wireless communications. Through its flexibility and adaptability ad hoc networking will allow for new scenarios in wireless communications. A Mobile Ad Hoc Network (MANET) consists of a set of mobile devices, usually referred to as nodes, which transfer to and forward each others packets to form a multi-hop network, acting concurrently both as an end and an intermediate system. The inherent decentralized nature of ad hoc networks makes the use of typical networks protocols almost impossible. Thus a great deal of effort has been made into designing new protocols on the various layers of the OSI stack, in particular for the lower layers (MAC and network).

On the MAC layer most of the initial work was focused on nodes with omni-directional links. Jurdak et al. [1] have provided a comprehensive survey of omni-directional MAC protocols. More recently the use for directional antennas in ad hoc networks has been proposed. Smart antenna systems which can beamform in specific directions in microseconds can allow for spatial multiplexing and thus significantly reduced interference. Several new solutions for medium access control in ad hoc networks using directional antennas have been proposed. These protocols are summarized in [2]. Despite the impressive amount of protocols proposed, none of the them makes provisions for multiple data links. Bao et al. have proposed a protocol utilizing transmission scheduling in ad hoc networks in [3], but their work lacks multi-link support.

In this paper we propose an algorithm that can manage multiple data links and antennas on a single node. So far literature has only considered nodes with only one data link (either omni-directional or directional). However the use of mobile ad hoc networks in maritime and avionic applications makes the existence of much more complicated nodes necessary. The need to serve a significant amount of time sensitive applications, along with bandwidth intensive passenger entertainment ones, makes it imperative for nodes to be equipped with optimum throughput, maximum reliability and long range. Current protocols for MANETs include functionality for multi-link support, but not for operational scenarios as dynamic as those present in networks studied in this paper. Here the presence of multiple directional antennas for each data link, can cause a node to create arbitrary connections with its neighbors. These connections can constantly change. Thus an algorithm is required to manage these antennas.

The applicability of Mobile Ad Hoc Networks in avionic environments is investigated in the ATENAA project. This represents an innovative applications where MANETs are studied in a three-dimensional, highly mobile environment, where a lot of the traditional Ad Hoc Networking concepts (e.g. the need low power consumption) are of minimal significance, while others (e.g. maximum network reliability) become of paramount importance.

In such applications a node might typically consist of an omni-directional radio link and one or more directional links of various types. An algorithm located between the Network layer and MAC sub-layer that aims to alleviate this issue is introduced here. It should be noted that the functionality of this algorithm should be included in the Data Link Layer of the OSI stack and it is proposed here as a separate entity for clarity reasons. The reason for providing an intermediate layer is to ensure compatibility with existing solutions and not performing major modification on either the network or the data link layers. Additionally this algorithm incorporates a solution for aligning two directional antennas using the omni - directional link as an out of band signaling medium. While the use of this algorithm provides a form of simplistic directional medium access control, it is anticipated that each terminal will utilize a more intricate solution for the MAC

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layer to enhance channel use efficiency, since this handshake is designed as an alignment method and is not meant to replace the much more elaborate medium access control solutions, which are available. The rest of the paper is organized as follows. In section 2 the concept and the operational principle of the Advanced Link Management Algorithm (ALMA) are described.

Section 3 provides a more detailed look into the implementation of ALMA, while Section 4 presents initial simulation results obtained from the OPNET simulator. Finally Section 5 summarizes our work and provides some concluding remarks.

2 MULTIPLE MAC LAYERS

This paper introduces a novel algorithm for managing multiple MAC layers and data links that may be present in a single wireless node. All interfaces are assumed to be wireless. At least one of them must be omni-directional, while others may be directional. More than one directional antennas of the same type may be present. It is assumed that each directional antenna is either steered or switched and has limited Field Of Regard and thus can only point to a specific portion of the space. However the coverage of more than one antenna of the same type may overlap. In this case it is responsibility of the MAC layer of each terminal to provide appropriate medium access control between the two overlapping antennas. All nodes are assumed to have knowledge of their geographical position though a separate mechanism (such as GPS). Finally it is assumed throughout this paper that each terminal has its own separate MAC layer which can communicate directly with ALMA. If a unified MAC layer for antennas an entire data link system exists, and then is must be able to provide all the needed information to ALMA. Fig.1 depicts a typical node with multiple interfaces and antennas.

Throughout this paper we will use the term terminal to denote the subsystem comprising of a single switched or steered antenna, along with its modem and physical control functions, which can establish a single communications link with another node (the antennas are assumed to have one main lobe only). With the term data link system we imply the sum of terminals of the same technology that are available on the node. Hence an optical data link system might consist of 2 or more optical terminals.

To manage the multitude of terminals available we introduce ALMA, a sub-layer which resides between the Network and MAC layers of the OSI protocol stack. It is assumed that the network layer would have already decided (using QoS parameters) which data link system is to be used. The reason for delegating the link choice to the network layer is that the routing protocol should be aware of the links used for each path, since the data links may be completely different in terms of transmission range and throughput. Thus the link selection for each path should be made at the network layer and not by ALMA, since in this case a selected route but not be possible due to link availability or range constraints. ALMA may utilize additional information from the network layer to sort packets to the various data link systems. The method used here utilizes a special IPv6 extension header. IPv6 extension header offer flexibility at minimum overhead. A node that cannot identify an extension header disregards it and continuous to process the packet. The extension header includes a field that defines which link is to be used for the packet transmission. The subtleties of this extension header are not explained here. It is up to ALMA to decide then which terminal is necessary for transmission (in case of a directional data link) and determine its status. To accomplish this, a state table is maintained within ALMA and containing an entry for each terminal and various information regarding its status. More information about this table can be found in [4]. Additionally ALMA provides an algorithm (illustrated in Fig.2) for aligning the directional terminals through the use of an omni-directional link.

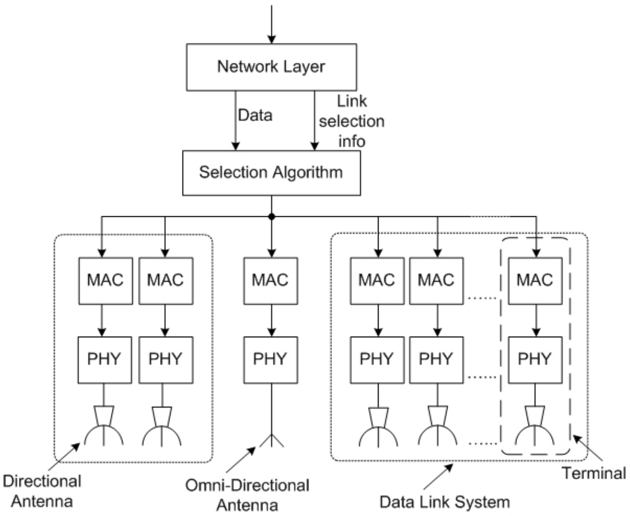

Figure 1 – Node with directional and omni-directional links and multiple terminals.

This algorithm draws inspiration from the DMAC protocol proposed by Ramanathan et al. in [5], but uses out-of-band signaling through the omni-directional link to achieve increased efficiency. It is assumed that the omni-directional link range is at least equal to that of any available directional link on the node. This is a valid assumption in practical applications, where a VHF omni-directional link is available (e.g. in aeronautical telecommunications)as well as one or more directional microwave links. If a directional link has a greater transmission range than the omni-directional link (e.g. this might be true for a satellite link.) than either that link must posses its own alignment method as part of its own dedicated MAC protocol (in this case a mechanism is provided to disable link management through ALMA for such a link.) or a mechanism similar to the one proposed in [6] must be provided where the alignment handshake is disseminated through multiple hops using the

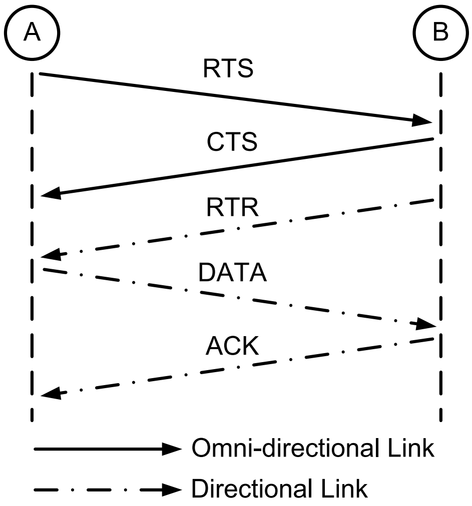

Figure 2 – RTS/CTS handshake for directional link alignment

Omni-directional link until it reaches the destination node. The latter method suffers from the fact that the directional range cannot be known at any given time and thus only an estimate can be made about which node to contact using the multi-hop handshake. However to establish communication, the antennas on both nodes will have to be aligned and the link tested, which will require a significant investment in network resources, without providing a guaranteed result, and thus might in the long term result in a reduction in network connectivity. The ALMA alignment algorithm consists of a signal exchange between the two nodes using both the omni-directional (at first) and the directional links.

The A-B handshake process is performed as follows:

1. The sender (A) dispatches an RTS signal through the omni-directional link. This signal notifies the receiver (B) that A wishes to communicate with him and that he should beamform to his direction.

2. B calculates which directional terminal is needed to communicate with A and then checks if that antenna is available. The needed terminal is calculated using the two nodes positions and the field of regard of each terminal. If an appropriate terminal is available B replies with a CTS message informing A that it has beamformed to him and steers the appropriate terminal in the needed direction. If the needed terminals is not free B includes that information in the CTS messages along with a time projection on when the terminal will be free. Obviously this time interval must be within a specified threshold (which should be different for specific applications), otherwise the packet should be dropped.

3. After B beamforms to A, B transmits a directional Ready To Receive (RTR) signal. This signal is necessary to verify that both terminals have beamformed correctly.

4. When A receives the RTR signal it begins transmitting data directionally to B.

When transmission completes and B has received all data successfully, it returns a directional ACK signal to A. During the remainder of the communication it is assumed that the terminals are able to track each other without requiring continuous repetitions of the handshake process. However in networks where nodes move randomly in constantly changing trajectories such a mechanism might be required. In the aeronautical environment for which ALMA was developed such functionality can be accomplished by the ADS-B application. ADS-B is an application which broadcasts an aircraft geographical position along with each velocity vector and various other technical information to its one-hop neighbors. ADS-B updates are issued on varying time intervals (from 2 per second to 1 every 5 seconds) depending on the flight phase. This is information can be used by ALMA, to update the tracking of active terminals.

ALMA was designed with scalability and link-independence in mind. This means that it can support N different data link systems, each utilizing Mi (where i = 1 to N) number of antennas and that the functionality of the algorithm is independent of the lower layers used in each link. However ALMA requires that the lower layers must be able to provide some information regarding the status of each antenna (e.g. if the antenna is currently busy, or where the antenna is currently pointing).

3 IMPLEMENTATION

As mentioned in section 2 ALMA will need to maintain a state table with entries for all terminals it manages. Each entry needs to have at least the following fields:

- ◊ *Terminal ID* – Identifies each terminal uniquely
- ◊ *Link Type* – Identifies to which data link system type this antenna belongs.
- ◊ *Status* – This field is an input from the corresponding terminal and shows if the terminal is currently busy (transmitting data), is pointing to a specific destination or is in idle state.
- ◊ *Point* – Contains the target coordinates at which the antenna currently points.
- ◊ *Terminal FoR* – Holds the Field Of Regard for this terminal.

The Status, Point and Terminal FoR fields are used by ALMA to determine which terminal to use. Obviously the selected terminal must belong to the Link Type specified by the upper layers. The decision mechanism can vary from implementation to implementation according to the applications needs.

Two frame types are defined for ALMA, the data frame and the control frame. The general format of the frame can be seen in Figure 3. The version field identifies the ALMA version used, the type field identifies whether this

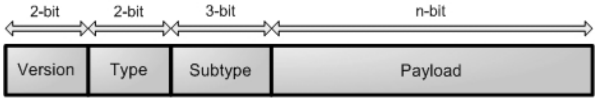

Figure 3 – ALMA data frame format

is a data or control frame. ALMA utilizes several control messages to accomplish the handshaking needed to align the directional terminals. These message use the control frame. The subtype field identifies the specific signal type in case of a control frame. Valid subtypes are the CTS, RTS and RTR signals. Finally the payload is the data as received by the upper layer in case of a data frame, or as needed in case of a control signal. The payload for the control signals must include all the information to ensure the necessary functionality. This in an RTS message, includes the link which is to be aligned and the coordinates of the communication initiator. In a CTS message it should include whether the response is positive or negative and if negative how long it will take before the needed terminal is freed. The RTR message is simply a beacon and needs no payload. It's reception itself is enough to initiate communication.

When a new packet arrives to ALMA it initially sorts the packet according to the link it is predefined to use. The simplest case is when a data packet needs to be transmitted through an omni-directional link. In this case the packet is simply forwarded to the appropriate lower layer. The handling of a data packet destined for a directional link is more complex. First of all, an antenna that can (due to its tracking limitations) point to the destination node for that link must be found. Then it must be determined if this antenna is free or busy transmitting other packets. If none exists (and will not be freed in a reasonable amount of time) then the upper layer must be notified of the link's unavailability (perhaps the packet may be re-forwarded to ALMA using a different link selection this time). An additional selection criterion that must be weighted is the direction of each antenna. If antenna A is free but needs to be aligned with the destination node and while antenna B, which point to the correct direction, is currently busy but will be available in an acceptable time frame, then B is the preferred choice. If an antenna is found and it is correctly aligned then the packet is forwarded directly to the appropriate lower layer. If not then the RTS/CTS handshake must be performed. In this case an RTS signal is dispatched through the omni-directional link to the destination node, and the corresponding packet is queued for dispatch to the appropriate MAC layer. The RTS signal includes A's geographical coordinates, and velocity vector, which are essential for B to calculate the needed antenna to communicate with A. In case of a positive response then the initiator beamforms to the direction of the destination and waits for the RTR message. If the RTR message is not received within a predefined time interval the link is deemed unavailable and the upper layer is informed. If the RTR message is received then transmission is initiated. As mentioned previously a link might disable the handshaking mechanism if it wants to use its own alignment method.

The receive algorithm is significantly simpler. A data packet is stripped off its frame and passed on to the upper layer. If a RTS signal is received it is processed (the availability of the needed antenna is determined) and the appropriate CTS is prepared. If a CTS and RTR signal is received, it is processed and the appropriate packet is removed from queue and processed accordingly by either continuing with the handshaking process, or beginning transmission.

4 SIMULATION RESULTS

To validate our results we have modeled ALMA in the OPNET simulator and performed several simulations to ensure its functionality and adequate performance. A simple implementation of the ALMA was coded for these initial tests, which uses three data link types, each of which had one terminal. The first data link is an omni-directional data link system similar to an aeronautical VHF data link. The other two data link systems are two incompatible (frequency-wise) microwave links(in this example one link in the L-band and one in the Ka-band are used). Both of these links utilize smart antennas to achieve directional communication. The L-band link has significantly lower throughput than the Ka-band link. Using only one directional terminal of each data link system does not require the full ALMA capabilities however it is sufficient to demonstrate the basic functionality and concept. The AODV routing protocol was used in all scenarios to forward traffic to the destination nodes.

The first simulation scenario is as follows: Node A wishes to communicates initially with a node B through its Ka-band link and at the same time with a node C using its L-band link. Nodes B and C are located in opposite directions from A. These nodes are part of a 5x5 rectangular mesh, and all are identical. Both B and C are 3 hops away from A. All nodes move at relatively high speeds (several hundred kilometers per hour) in random straight lines. The distance between two nodes in the mesh is 100 kms. All nodes are in the same altitude and the field-of-regard for both directional antennas is assumed to be $\pm 180^o$ on the x-y plane. The remaining nodes exchange only sporadic http traffic in random patterns (both destination and link-wise). Initially no directional antennas are aligned to any node. The scenario is that B and C receive the same 5 MB video stream from A. The video stream is buffered in each destination node and thus may be transmitted at the maximum speed for each link. Then after a short period of time B and C receive the same file again, this time though B receives the stream through the L-band link, while C through the slow omni-directional link. It should be noted that the stream is not multicasted to B and C, but unicasted using two different links at the same time. Figure 4 shows the simulations results for the aforementioned scenario. The graph shows the traffic received by nodes B and C. We see

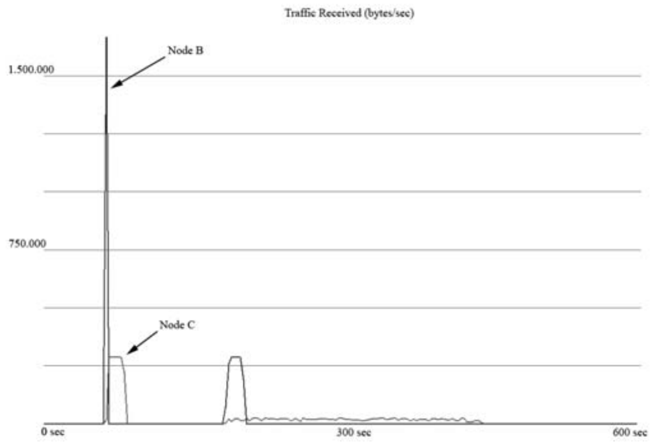

Figure 4 – Simulation results for concurrent L- and Ka-band link usage

that ALMA aligns both all the directional links along the paths correctly and achieves directional communication using both links at the same time. Transmission using the Ka band link completes almost instantly, while the L band link needs significantly more time. At the second phase the A's L-band link is correctly re-aligned with B and communication is again successful as is the omni-directional communication with C. The performance of the L band links is similar to the first transmission while the omni-directional link needs several minutes to complete the download.

Figure 5 explores another scenario where the topology remains the same as before, but now node A transmits the video stream using the L-band link, initially only to node B, then to B and C at the same time and then only to C. The results show two spikes, which occurs when is transmitting only to B or only to C. However the most interesting area of the graph is when concurrent transmission to both nodes using the same link is taking place. Here the link must be successfully realigned continuously, depending on the order with which the packets arrive from the upper layer. This results in a drop in the maximum throughput (as is evident by the graph), which however is only 20-30 Kbytes/sec and perhaps more importantly for some applications a small jitter in the arrival of the packets. It should be noted however that the impact on link performance is mostly affected by the steering speed of the antenna. In case a slower mechanically steered antenna is used, the resulting performance loss would be significantly larger. The important conclusion that ca be reached, is that the alignment handshake used in ALMA does not significantly affect the acquisition time for a new destination node. The jitter created by the constant antenna rotation may present a serious problem for streaming applications. Its effect may be reduced by buffering and queuing packets in the originator, in order to optimize antenna movement. It is important to note that when a phased array antenna is acquiring a moving target, most of the time needed to align the terminal is not used for moving the main lobe, but for stabilizing it and tracking the target node.

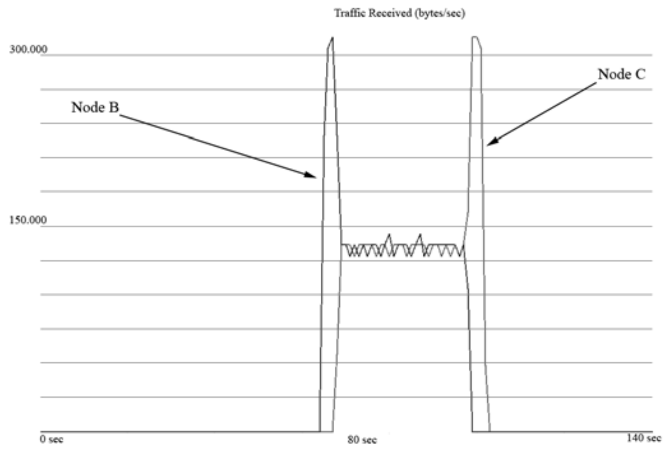

Figure 5 – Simulation results for L-band link switching between two nodes

5 CONCLUSIONS

This paper presented a solution for managing multiple wireless interfaces, each utilizing multiple antennas in ad hoc networks. The proposed algorithm is compatible with existing MAC layer solutions and requires only minimal changes to some routing protocols. The solution has been modelled in the OPNET simulator and tested in several scenarios. The simulation results verify the algorithms functionality using 3 interfaces. Future simulation results will include more complex scenarios with more complicated node types, like including multiple antennas of each data link and limiting the field of view for these antennas. Additional modules for ALMA are being developed which will allow the optimization of packet queuing and thus maximum throughput and minimum packet jitter.

6 REFERENCES

[1] R. Jurdak, C.V. Lopes and P.Baldi, "A survey, classification and comparative analysis of Medium Access Control protocols for ad hoc networks", IEEE Communications Surveys and Tutorials, 1st quarter 2005, volume 6, No.1, 2004.

[2] R. Vilzmann and C. Bettstetter, "A Survey on MAC Protocols for Ad Hoc Networks with Directional Antennas", In Proc. EUNICE Open European Summer School, Colmenarejo, Spain, July 6-8, 2005.

[3] L.Bao and J.J Garcia-Luna-Aceves, "Transmission scheduling in ad hoc networks with directional antennas", Proceedings of the 8th annual international conference on Mobile computing and networking, 2002, pp.48-58.

[4] K. Karras, M. Iordanakis, "ALMA Technical Report", TEI of Piraeus

[5] R. Ramanathan, J. Redi, C. Santivanez, D. Wiggins and S. Polit, " Ad hoc networking with directional antennas: a complete system solution", IEEE Journal on Selected Areas of Communications, Volume 23, March 2005, pp.496-506.

[6] R. R. Choudhury, X. Yang, N. H. Vaidya and R. Ramanathan, "Using directional antennas for medium access control in ad hoc networks.", Proceedings of the 8th annual international conference on Mobile computing and networking, 2002, pp.59-70