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14. ABSTRACT
Active topology management in the Airborne Network (AN) can provide improved overall network performance, efficiency, and scalability. Topology management and control in airborne networks are critical due to the high degree of platform dynamics involved. The RF links that form an airborne network must be capable of being established and reconfigured rapidly in response to aircraft joining and leaving the network, aircraft changing flight paths, and the changes in mission information flows, among other things. Additional technical challenges stem from the fact that the airborne nodes will use multiple directional and omni-directional antennas with differing antenna patterns. In this paper we present a Mission Aware Topology Control (MAToC) solution for the Airborne Network. MAToC is comprised of deliberative and reactive topology planning components.

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Topology Control within the Airborne Network Backbone

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ABSTRACT

Active topology management in the Airborne Network (AN) can provide improved overall network performance, efficiency, and scalability. Topology management and control in airborne networks are critical due to the high degree of platform dynamics involved. The RF links that form an airborne network must be capable of being established and reconfigured rapidly in response to aircraft joining and leaving the network, aircraft changing flight paths, and the changes in mission information flows, among other things. Additional technical challenges stem from the fact that the airborne nodes will use multiple directional and omni-directional antennas with differing antenna patterns. In this paper we present a Mission Aware Topology Control (MAToC) solution for the Airborne Network. MAToC is comprised of deliberative and reactive topology planning components. MAToC utilizes a distributed protocol for airborne nodes for ad-hoc exchange of respective flight plan. Deliberative mode planning uses the collected flight plan information to assign optimal power, channel and bore-sight direction to the airborne antennas. Deliberative MAToC uses graph coloring algorithms for channel and time slot assignment and uses geometric optimization methodology to assign antenna powers to maximize Signal to Interference and Noise Ratio (SINR). In the reactive mode, MAToC is responsible for link monitoring and link repair for, fault-tolerant topology construction.

1 INTRODUCTION

There are ongoing efforts to develop an Internet Protocol (IP) based airborne network, in order to interconnect mobile air platforms and provide interconnectivity with space and terrestrial networks. As shown in Figure 1, AN will need to provide connectivity between the satellite network and already operational airborne subnets (sensor networks, Joint Airborne Tactical Edge Networks, JAN-TE), legacy airborne links, ground and sea based mobile ad-hoc networks, and the existing fixed terrestrial internet. AN will enable Network Centric Warfare (NCW), where the terrestrial forces, airborne intelligence and the command and control (C2) stations will be linked.

The Air Force is also investing the Objective Airborne Gateway (OG), which will provide ground and surface forces access to the data networks via the AN. OG can also serve as a relay for ground forces that do not have line of sight communication due to terrain obstruction.

United States Navy's Automated Digital Network System (ADNS) as it exists today uses satellite links that presents problems of high latency and low bandwidth. ADNS provides an IP backbone network, but in order to realize DoD's vision of complete network centric operations, Air Force airborne network is absolutely critical.

In addition to providing military with information superiority, the utility of AN can not be discounted on the

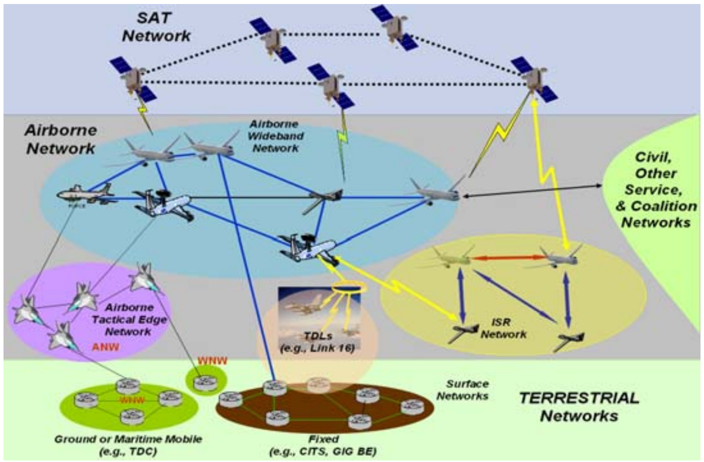

Figure 1: Airborne Network conceptual diagram.

commercial front. AN will be used to interconnect commercial airliners and Air Traffic Control (ATC). It will form a medium to exchange navigation, localization and surveillance information between airliners and ground stations. AN can potentially enable aircrafts to self coordinate landing and taking off in areas of high air traffic, thus distributing the air traffic control which at present is highly centralized and inefficient. An excerpt from the MIT Technology review article [1] explains this well.

"The technology that underpins the air traffic control system hasn't changed much in a half-century. Planes still depend on elaborate ground-based radar systems, plus thousands of people who watch blips on screens and issue verbal instructions, for takeoffs, landings, and course changes. The system is expensive, hard to scale up and prone to delays when storms strike.

An entirely different approach is possible. Each plane could continually transmit its identity, precise location, speed, and heading to other planes in the sky via an airborne network. Software would then take over, coordinating the system by issuing instructions to pilots on how to stay separated, optimize routes, avoid bad weather, and execute precise landings in poor visibility."

In addition to this, AN can also be used to provide wireless internet coverage over a wide urban area. A good article on this futuristic application can be found at [2].

As shown in Figure 1, AN will interoperate with various networks for a variety of military and commercial applications, therefore, DoD mandates a packet based IP network for consistency.

Topology is the interconnecting pattern of nodes in a network. In a wired network, the topology is essentially static, determined by physical connections between nodes. In most commercial wireless networks, the topology is largely static as well. Since Cellular and WiFi users are mobile, their point of connection may change, but the underlying network is typically a fixed set of cellular towers or WiFi access points. Emerging commercial ad-hoc or mesh based wireless networks are self-forming by nature, and active topology management can provide improved overall network performance, efficiency, and scalability. Topology management and control in airborne networks are more critical due to the high degree of platform dynamics involved. The RF links that form an airborne network must be capable of being established and changed rapidly in response to the aircraft joining or leaving the network, aircraft changing flight paths, the changes in mission information flows, etc. These changes must be implemented in such a way as to minimize impacts to the performance of the network and with little or no operator involvement. There are two basic forms of topology control: control by changing the transmit power or by redirecting antennas. In networks which utilize omni-directional antennas, which would typically be the case in networks consisting of tactical aircraft, the only means of controlling the topology is by varying the transmit power. While keeping a high transmit power may improve connectivity and reduce the number of hops required through a network, it also increases interference and complexity of routing. In networks which utilize a fixed number of directional antennas, which would typically be the case in high bandwidth backbone regions of the airborne network, the only way of controlling the topology is to redirect one or more of the available antennas.

As spelled out in [3], topology management can result in higher network capacity, lower energy consumption at each node, higher quality communication in airborne networks. If topology management can be done in a distributed manner, it may result in extending the same protocols to a greater number of nodes without significant increases in the computational overload.

There are a number of existing topology management strategies and protocols in the literature. [3] provides a good overview of the topology control literature: Location based [Rodoplu and Meng (R&M) protocol, Local Minimum Spanning Tree (LMST) protocol], direction based [Cone Based Topology Control (CBTC) protocol, Distributed Relative Neighborhood Graph (DistRNG) protocol], neighbor-based topology control [K Neighbors (KNEIGH) protocol, eXtreme Topology Control (XTC) protocol], protocols dealing with node mobility [Local Information No Topology (LINT) protocol, Mobile CBTC] and level-based topology control protocols [COMmon POWer (COMPOW) protocol, CLUSTERed POWer (CLUSTERPOW) protocol, K NEIGHbors LEVel based (KNEIGHLEV) protocol]. All of the above topology control protocols have been developed for traditional wireless ad-hoc networks and low power sensor networks; there has not been much research on topology control protocols specific to the airborne network scenario.

2 AIRBORNE NETWORK CHARACTERISTICS

Airborne Networks will differ from existing mobile ad-hoc networks, and sensor networks. AN will employ Line of Sight (LOS) wireless links and the topology of the airborne network might change when the airborne platforms turn (platform banking), or when there is an obstruction of LOS between radio antennas (antenna shadowing). Antenna shadowing can cause slow fading of the wireless channel. Link loss can also result due to dead zones caused by the wake vortex of the airborne platform [4]. The airborne communication links should be of the order of 150-350 nautical miles [5] in length, thus latency and path losses on these links can be significant. Also note that in long range wireless directional communication, a little increase in the beam width can cause significant increase in the reachability volume of the radio link. Airborne links could be exposed to intentional jamming, which can have severe consequences on security and routing. Also, each airborne node can have different radio amplifiers and antennas. Topology control protocol will need to be aware of the physical layer capabilities at each node. The heterogeneity of nodes and links in AN will imply different communication capabilities, different error rates and capacities and the presence of unidirectional links. Multi-path effects should be negligible due to the operation of AN in free space. Therefore path loss would be a function of distance only.

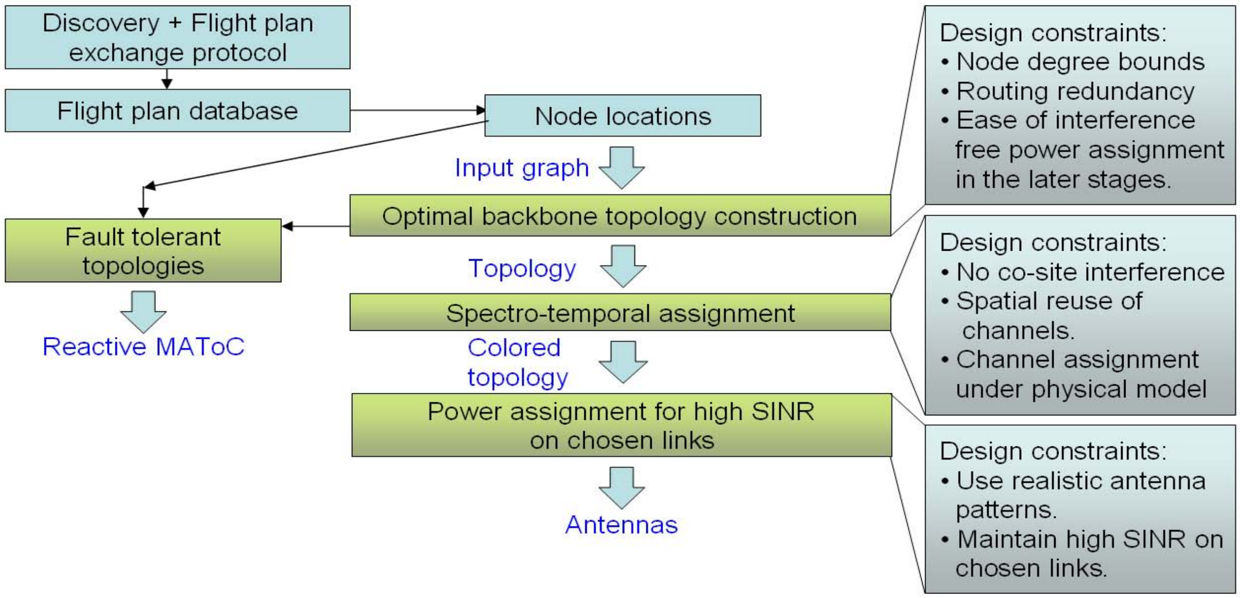

Figure 2: Different Stages of MAToC's Deliberative Planning Architecture

The transmitter power of the airborne nodes could be significantly higher than battery operated MANET nodes which and might also be equipped with global positioning system (GPS), navigation hardware and might have multiple directional antennas.

3 MOBILITY AWARE TOPOLOGY CONTROL (MAToC)

Figure 2 illustrates different stages of the MAToC deliberative topology planning architecture. The proposed Mission Aware Topology Control (MAToC) sits between the routing and the MAC layers. MAToC has two components: a deliberative planning component and a reactive planning component. The airborne nodes use the omni-directional antennas to share mission flight plans and Air Tasking Orders (ATOs) with each other. There are several ways MAToC interacts with different routing protocols: MAToC uses the Hello/Ack feedback mechanism of the proactive routing protocols like OLSR and OSPF for monitoring links. The time dependent topology planned by deliberative MAToC is shared with proactive routing protocols resulting in infrequent topology control message exchange at the routing layer. The reactive protocols like (AODV, TORA etc.) can also benefit from MAToC deliberative topology planning. The route maintenance Hello/Ack mechanism of the reactive protocols is used as link monitoring feedback. Based on the knowledge of flight plans, the deliberative MAToC plans optimal backbone topologies with constraints on node degrees, required redundancy in routing and interference minimization. To avoid co-site interference and ease of SINR maximization MAToC assigns spectro-temporal slots to each link in the topology. The assignment ensures spatial reuse of channels and TDMA time slots and orthogonal assignment of links that are within each other's interference range. The number of spectro-temporal slots that can be assigned is dependent on the availability of communication resources.

Once the slots have been assigned, the potential interfering links can be identified. The last step of deliberative MAToC computes the optimal power levels for each antenna. The optimization routine is a computationally efficient geometric program that maximizes the minimum SINR in the network. Geometric optimization techniques have been employed for Quality of Service (QoS) guarantees in cellular and multi-hop networks. The optimization routine can be used for any kind of antenna patterns. During the optimization it is possible to attach a higher importance to links that are critical or are carrying high priority data. In our current approach we maximize the worst case SINR, thus providing worst case guarantee on QoS for every link in the topology

When MAToC perceives a loss in link quality it locally repairs the link by increasing power and beam width in an incremental closed loop fashion. Loss in link quality may result due to jamming, unexpected platform or terrain blockage. To counter malicious jamming reactive MAToC may chose to create fault-tolerant links to mend the overall topology. The fault tolerant link creation algorithm involves minimal communication overhead and the changes made to the topology are local such that the non-affected links are able to operate under optimal or near-optimal mode.

3.1 Optimal Backbone Topology Construction

The topology control protocol will need to maintain a reliable communication backbone over the theater of operations. It must make sure that the backbone is always connected, there is no co-site interference at any node, power assignments at the directional antennas considers the resulting interference with other transmitting links on the same frequency.

The design constraints to be considered at the topology construction stage are degree bounds at each node,

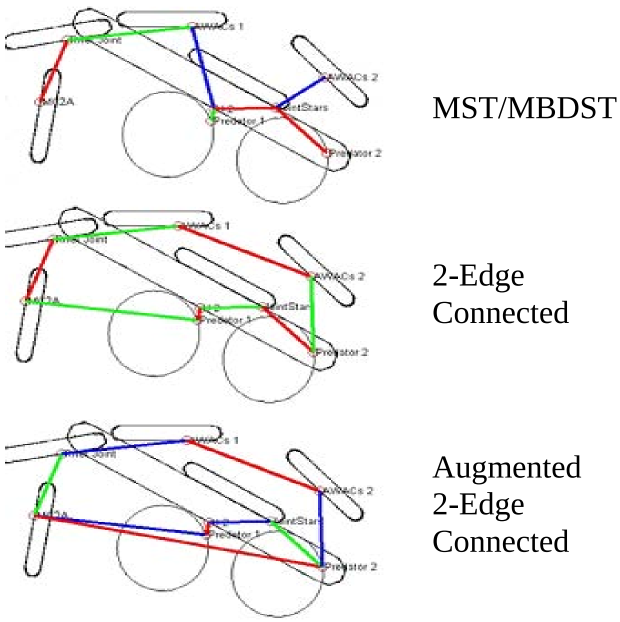

Figure 3: Illustration of Multiple Possible Topologies for the Same Notional Node Positions

availability of redundant paths between each pair of nodes and ease of interference free power assignment in the later stages of optimization. We have tried three different ways of constructing topologies in this stage, Minimum Spanning Tree (MST), Minimum Bounded Degree Spanning Tree (MBDST), and Minimum Bounded Two Connected Topology. Figure 3 illustrates these three different topology methods for the same notional set of node positions. The Minimum Bounded Degree Spanning Tree (MBDST) problem is defined as follows: Given a simple undirected graph $G=(V,E)$, a cost function $c: E \rightarrow \Re$ and a degree upper bound B_v for each vertex $v \in V$, find a spanning tree of minimum cost which satisfies all the degree bounds. The minimum bounded degree spanning tree problem is NP hard in general. This can be shown by reduction to the Hamiltonian Path problem, [6]. Now let OPT be the cost of an optimal solution to the MBDST problem. An $(\alpha, f(B_v))$-approximation algorithm is an algorithm which returns a spanning tree T with cost at most $\alpha.OPT$ and $d_T(v) \leq f(B_v)$ for all v, where $d_T(v)$ denotes the degree of v in T. We have implemented $(1, B_v+2)$ and $(1, B_v+1)$ approximation algorithms for the MBDST problem, as presented in [6]. The tree based topologies have lower interference due to fewer links, but they are also less robust due to a single point of failure.

3.2 Frequency Assignment using Edge Coloring

In [7], there is a linear-time edge-coloring method for graph of maximum degree 3 using 4 colors at most. Under this assumption of a node model with a maximum of three outgoing directional links, the method in [7] follows two steps. The first step is to decompose an input graph into a *forest*, i.e. a set of trees, and a collection of node-disjoint cycles. The second step is a greedy approach based on a set of rules to color the forest, followed by coloring the cycles. Coloring edges of a tree of the forest follows the order of the depth-first-search. Based on the edge colors of the forest, coloring each cycle follows a carefully chosen starting node and traversing orientation. We describe only the relevant rule to our topology here: after coloring the forest, if there is a node *u* in a cycle that is not incident to any edge of the forest and suppose that edge (*u*,*v*) is of the cycle, then start the tour from *v* but away from *w* and use the available color of lowest index for the edges of the cycle.

3.3 Transmission Power and Boresight Assignment

We make the following key assumptions to formulate our problem of computing the optimal power levels and boresight directions:

(a) The communication network consists of point-to-point dedicated bi-directional links.

(b) We also assume that each node in the network is capable of hosting multiple such links depending on the capabilities of the platform. Since the links are full-duplex, communication between a pair of nodes connected by a link can proceed in both directions simultaneous without interference. However, it can still suffer interference due to communication proceeding on other such links in the neighborhood.

(c) If at any time t nodes i and j are communicating with each other, then one of the antennas on node i must point towards node j and vice versa. Therefore, at any time if the desired underlying undirected communication graph $G_{\mathrm{opt}}(V(t), E(t))$ is specified, then the problem of computing the antenna pointing directions is automatically solved.

(d) A transmission or reception between node i and node j along a dedicated link does *not* interfere with any other transmission from either node along another dedicated link.

Having stated the assumptions, we present the conditions under which a successful communication between a pair of nodes is possible. For easy of notation, the dependence on time t is dropped hereafter. Let us introduce some notation first. Let $g_{t,i,j}(\bar{n}_i,\bar{n}_k)$ denote the transmitter gain in the direction from $\bar{n}_i$ to $\bar{n}_k$ when the boresight is pointing from $\bar{n}_i$ to $\bar{n}_j$. Similarly, $g_{r,j,i}(\bar{n}_j,\bar{n}_k)$ denote the receiver gain in the direction from $\bar{n}_j$ to $\bar{n}_k$ when the boresight is pointing from $\bar{n}_j$ to $\bar{n}_i$. Node $\bar{n}_i$ can communicate with $\bar{n}_j$ only if *both* of the following conditions are true [8].

The received power at node $\bar{n}_j$ is greater than a certain threshold $RX_{\min}$. In mathematical terms, we can write this conditions as follows:

$$\frac{p_t(i,j)g_{t,i,j}(\bar{n}_i,\bar{n}_j)g_{r,j,i}(\bar{n}_j,\bar{n}_i)}{d(\bar{n}_i,\bar{n}_j)^{\alpha}} \geq RX_{\min} \qquad (1)$$

Here, $p_t(i,j)$ is the power transmitted by $\bar{n}_i$ in the direction of $\bar{n}_j$, $g_{t,i,j}(\bar{n}_i,\bar{n}_j)$ is the transmitter gain at $\bar{n}_i$ in the direction of $\bar{n}_j$, $g_r(\bar{n}_i,\bar{n}_j)$ is the receiver gain at $\bar{n}_j$ in the direction of $\bar{n}_i$, $d(\bar{n}_i,\bar{n}_j)$ is the Euclidean distance between nodes $\bar{n}_i$ and $\bar{n}_j$, α is the path-loss exponent which is usually set equal to 2 for free-space communication, and $RX_{\min}$ is the received power threshold.

The signal-to-interference-and-noise ratio (SINR) at $\bar{n}_j$ should be greater than a certain threshold. Formally, this condition can be written as follows:

$$\frac{p_t(i,j)g_{t,i,j}(\bar{n}_i,\bar{n}_j)g_{r,j,i}(\bar{n}_j,\bar{n}_i)d(\bar{n}_i,\bar{n}_j)^{-\alpha}}{N+I_j} \geq \beta$$

Here, N is the noise power, and I_j is the total power in the interfering signals. If the network has a total of m nodes with indices belonging to the set $\{1,\ldots,m\}$, then the following is true.

$$I_j \leq \sum_{(k,l)\in E, k\notin\{i,j\}, l\neq j} p_t(k,l)g_{t,i,j}(\bar{n}_k,\bar{n}_j)g_{r,j,i}(\bar{n}_j,\bar{n}_k)$$

We assume in the above that a communication from node i to node j will not be subject to interference due to any communication originating from node i or node j, as well as any communication terminating at node j. In other words concurrent transmissions and receptions at the same node do not interfere due to appropriate shielding, frequency hopping or time scheduling. Therefore, in the worst case, the SINR requirement can be written as follows:

$$\frac{p_t(i,j)g_{t,i,j}(\bar{n}_i,\bar{n}_j)g_{r,j,i}(\bar{n}_j,\bar{n}_i)d(\bar{n}_i,\bar{n}_j)^{-\alpha}}{N+\sum_{(k,l)\in E, k\notin\{i,j\}, l\neq j} p_t(k,l)g_{t,i,j}(\bar{n}_k,\bar{n}_j)g_{r,j,i}(\bar{n}_j,\bar{n}_k)} \geq \beta$$

We assume that conditions (1) and (2) are necessary for node n_j to successfully receive and decode a signal transmitted by node n_i.

The overall optimization problem can now be posed as follows:

$$\min_{p_t(i,j),(i,j)\in E} \sum_{(i,j)\in E} p_t(i,j)$$

subject to the following constraints:

$$\frac{p_t(i,j)g_{t,i,j}(\bar{n}_i,\bar{n}_j)g_{r,j,i}(\bar{n}_j,\bar{n}_i)}{d(\bar{n}_i,\bar{n}_j)^{\alpha}} \geq RX_{\min} \quad \forall (i,j)\in E$$

$$\frac{p_t(i,j)g_{t,i,j}(\bar{n}_i,\bar{n}_j)g_{r,j,i}(\bar{n}_j,\bar{n}_i)d(\bar{n}_i,\bar{n}_j)^{-\alpha}}{N+\sum_{(k,l)\in E, k\notin\{i,j\}, l\neq j} p_t(k,l)g_{t,i,j}(\bar{n}_k,\bar{n}_j)g_{r,j,i}(\bar{n}_j,\bar{n}_k)} \geq \beta \quad \forall (i,j)\in E$$

$$p_t(i,j) \leq p_{\max} \quad \forall (i,j)\in E$$

The antenna gains $g_t(\square)$ and $g_r(\square)$ are dependent on the geometric locations of the nodes and the antenna models used which are not part of the decision variable set. Therefore, the above optimization problem is a linear program in $|E|$ variables where $|E|$ is the number of edges in the input topology. Notice that any antenna model can be used in the optimization and different models can be used in different antennas. The number of constraints is $2|E|$. Notice that $|E| \leq m(m-1)$. Thus, if the input topology is a tree then the number of decision variables and the number of constraints are both $O(m)$. Therefore, this problem is tractable even for a network with a large number of nodes.

It can be easily shown that for any combination of values of $RX_{\min}$, $p_{\max}$ and SINR, if the beam width is chosen narrow enough, feasible solutions are always possible. Also, our preliminary investigation has indicated that if the input topology is sparse enough, feasible solutions can be obtained.

3.4 Link Monitoring

One component of the reactive MAToC is local Link Monitoring. Every node monitors the Line of Sight (LOS) and Blocked Line of Sight (BLOS) links that are incident at it. In our current implementation architecture, MAToC receives feedback through the routing layer. Under normal operation the proactive routing protocol continually monitors each link incident at a particular node using Hello / Hello-Ack messages. In case the routing protocol does not receive Ack messages over a link that is active according to the deliberative topology plan, the proactive routing protocol informs MAToC about the inconsistency. The routing protocol also floods the network with a new Link State Advertisement (LSA) message, informing other nodes in the network about the missing link, so that the local perception of global topology present at other nodes is also updated accordingly. Note that the above method is one way of collecting feedback without adding extra communication overhead, the medium used is the proactive routing protocol. At the physical layer receiver SINR and Bit Error Rate (Bit Error Rate) are good indicators of link quality. In case a node observes that a link has fallen below acceptable SINR and BER values it activates the local link repair module of reactive MAToC.

3.5 Closed Loop Power Increments

In this link repair mode of operation reactive MAToC tries to increase the antenna power and beam width by small increments. This is done with closed loop feedback from the routing protocol. The deliberative topologies, spectrum, slot and power assignments are optimized for minimum interference and high network capacity. It is undesirable to increase power or beamwidth by large amounts because doing so may increase interference at other links thus reducing network capacity. For our implementation in every iteration the power is increased by 1dBm ~ 1.25 mW. The spectrum and slot assignment is done by the deliberative MAToC in order to reduce the amount of communication resources (bandwidth, Air time) used by the network, therefore it may be possible that there are unused channels and slots at a node. Under such circumstances the local link repair module can opt to use a new channel provided it does not disturb the equilibrium at other nodes in the network. The feasibility of using a new channel can be determined by reactive MAToC using the deliberative topology plan.

If a node fails to repair the lost link within a certain user defined TIME_OUT, the reactive MAToC decides to choose a backup link from the fault tolerant link database.

3.3 Fault Tolerant Topology Planning

To maintain a connected airborne network, backup network resources must be available to fill in the role of a problem link. Link failure is a common phenomenon in highly dynamic airborne network due to mobility and jamming. The consequence of such failure may result in lost of communications across the network or in the worst case putting the entire network in an unstable state. For link failure, a well-known approach for the protection is to maintain a secondary communication channel that does not share the same resources of the link it is trying to protect. For example, it may be possible that choosing a different channel may recover a link from failure. MAToC maintains Backup-Topology (BT) table at every node maintains a library of backup links to address the problem of lost connections.

To maintain connectivity of the networks against all possible link failure scenarios, a backup link is found for each optimal link in the network. Consider the following example: A link *e* in the optimal topology could become inaccessible due to some unexpected events. To find a backup link, the failed link *e* is temporarily removed from the input graph $G_{\text{input}}(V(t), E(t))$ and the backup is found using the modified input graph.

In our current implementation each node carries a backup topology table which contains backup links for each link in the optimal topology planned by deliberative MAToC. The construction of backup link must be accomplished with minimal changes to the remaining network. The optimization formulation for power assignment of backup topology is the same as the one used in deliberative power optimization except that the optimization variables vector only includes the two new power levels required to set up the backup link. The rest of the power levels are kept the same as in the case of the optimal topology. This is done to make sure that power changes required are minimal. Empirically we have observed that this strategy results in a suboptimal topology but has very low overhead.

4 EXPERIMENTAL RESULTS

In this section, we present the experimental results to illustrate the advantages of optimizing the antenna transmission power and how it improves performance. The experiments were conducted in QualNet. An abstract physical layer was used with a receiver sensitivity of 83dBm and the SNR threshold of the receiver of -83dBm. The background noise power is -100.97dBm. The MAC is a generic implementation that uses Carrier Sense Multiple Access (CSMA) to avoid packet collisions. The routing protocol used is Optimized Link State Routing (OLSR), which is optimized for mobile ad-hoc networks. The interval at which the HELLO packets are sent by OLSR for neighbor discovery (Hello Interval) is set at 800ms and each node dissipates the topology information at the routing layer every 5 seconds (Topology Update interval). The choice of OLSR is made in accordance with the design paradigm that MAToC will work with proactive routing protocols. Two Constant Bit Rate (CBR) flows were introduced in a simple four node network with two frequencies as shown in Figure 4. The first flow is from nodes 3 to 1 and the second flow is from nodes 4 to 2.

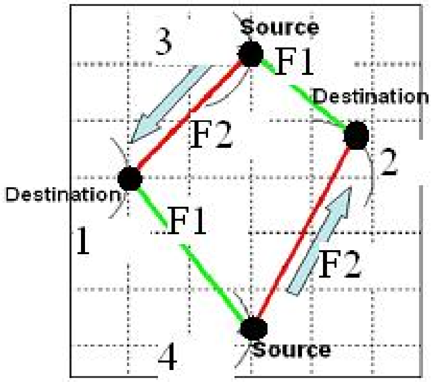

Figure 4: A simple four node scenario with two Constant Bit Rate traffic flows. There are two frequencies used in the network, F1 and F2.

We compared the number of packets delivered over both flows across the network. As seen in Figure 7, when a constant maximum transmission power is used there is a drop in the number of packets delivered whereas MAToC maintains stable packet transfer.

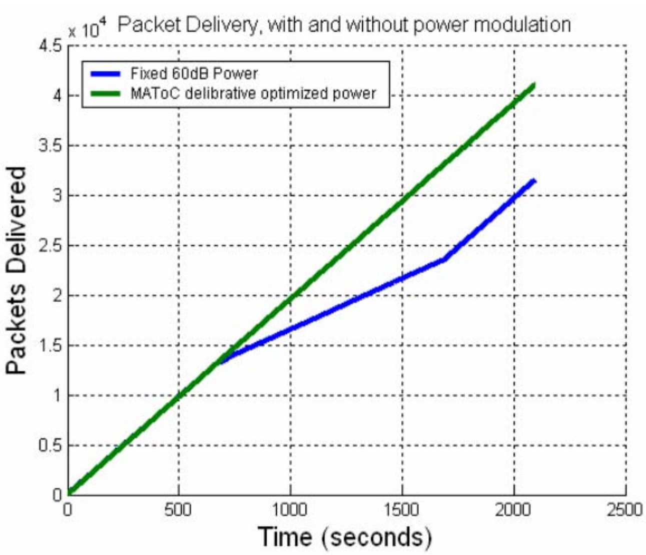

Figure 7: Packets delivered over time. Transmission power optimization allows MAToC to maintain the packet delivery rate by adapting to the interference.

As seen in Figure 6, the SINR at Node 2 without power optimization degrades for the interval between 700th second and 1700th second. The decrease in SINR is because of the side-lob effect. The geographic locations of the nodes at 1200 as seen in Figure 5, are such that the side lobe of the "F2" interface at node 3 points towards Node-2 and vice versa. This is the reason for increased interference at Node-2 from Node-3 for the case without power modulation. On the other hand, with power optimization, the power transmitted from Node-3 towards Node-4 along with "F2" interface is much lower than the one with fixed power. This mitigates the effect of Node-3's side lobe

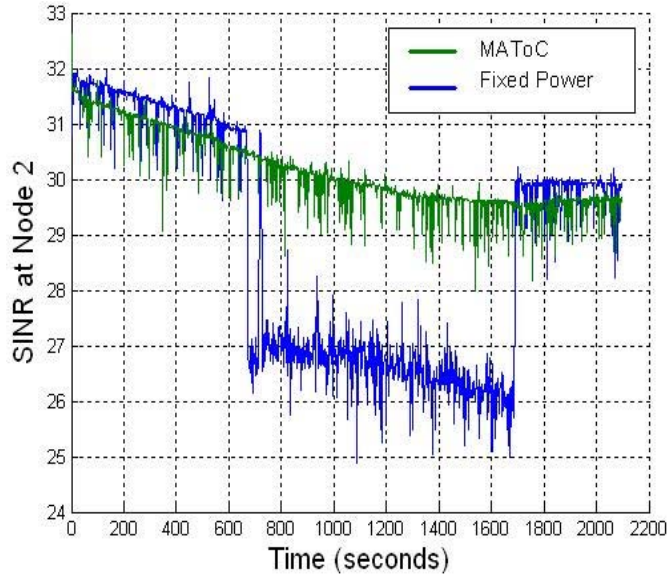

Figure 6: Signal to Interference and Noise Ratio (SINR) at Node 2. MAToC maintains higher SINR with a maximum power of 60dB, while a constant power of 60dB has higher interference.

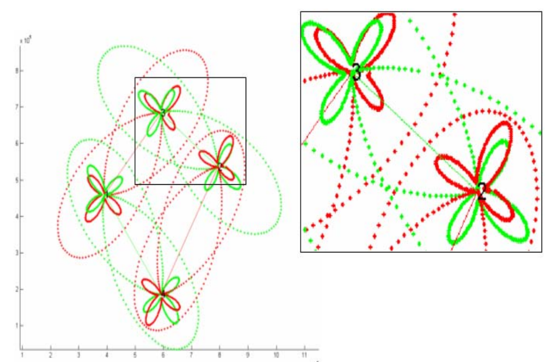

Figure 5: Directional antenna lobes at different nodes at 1200 seconds with a fixed power level of 60 dB for every antenna. On the right is shown an expanded view of nodes 2 and 3

pointing towards Node-2. The deliberative optimization can use any antenna pattern for optimizing the transmission power to improve the network bandwidth.

We have run experiments to visualize the benefits of reactive control by injecting an extra system loss of 13dB at each antenna present at every node, see Figure 8. This system loss can represent any unanticipated communication loss that might occur in the network due to effects such as weather conditions, occlusions and even frequency jamming. Since the deliberative optimization which was performed cannot account for such abnormality, the reactive mode must increment the power to compensate. The deliberative power that was set on the link might have been reduced to ameliorate interference effects in other parts of the network. The reactive mode

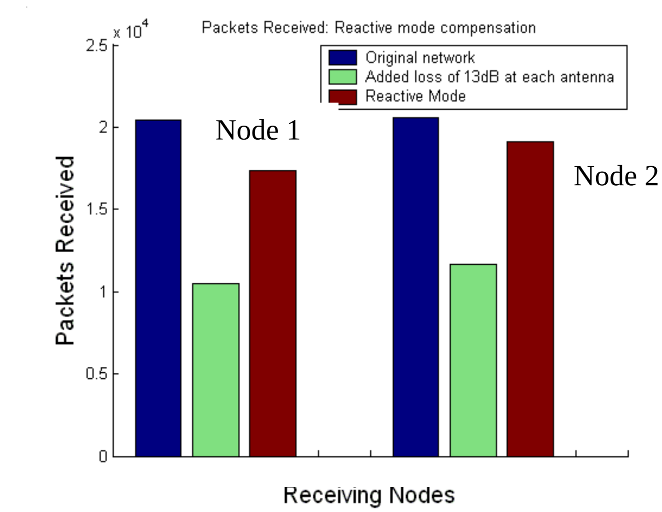

Figure 8: MAToC is used to repair the lost topology links when an unanticipated communication system loss of 13dB is introduced at every antenna.

can potentially increase the power up to the maximum power allowed on the communication platform. Once the link is re-established, the power is not boosted any further. In this experiment, the maximum power boost for any link is set at 10dB. It is also possible to restrict the power boost such that the maximum power used is below a threshold which depends on the communication platform. With the reactive mode topology repair, the number of packets received improves by 65% which is just 7% lower than before the introduction of the unanticipated communication system loss.

We also investigated the performance gain obtained while using fault tolerant backup topologies. In a five node topology shown in Figure 9 with a network flow from Node-2 to Node-3, a link loss is introduced between Node-3 and Node-4. A gain of 28% is obtained using the reactive link fault tolerance as seen in Figure 10.

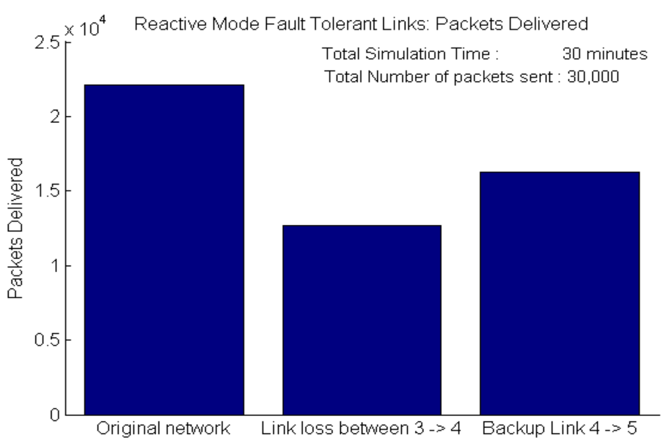

Figure 10: Reactive fault tolerant link strategy is used to compensate for a local link failure between Node-3 and Node-4 in the network shown in Figure 9. A backup link is established between Node-3 and Node-5.

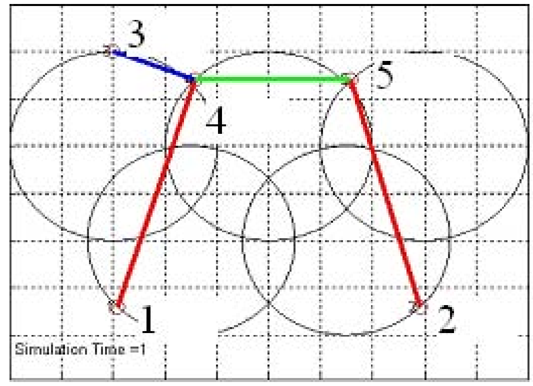

Figure 9: Network topology in a five node network.

5 CONCLUSIONS

In this paper, we present the Mission Aware Topology Control (MAToC) protocol for the tactical Airborne Network backbone. MAToC exploits the mission and mobility knowledge of the airborne nodes to create an optimized topology and also optimizes the transmission power to reduce worst case interference. MAToC can also optimize the frequency or slot-assignment to improve network bandwidth. We have shown through our simulations the reduced interference obtained with various deliberative and reactive algorithms in MAToC.

6 FUTURE WORK

In the future, we plan to extend MAToC to improve its adaptability to unforeseen interference. MAToC can adapt to traffic load in runtime thus increasing available bandwidth in an airborne network. In future our team will develop modules for seamless airborne node arrival/departure from the planned topology. In the deliberative mode we can accommodate further considerations for topology construction such as traffic requirements and improving the flow across the minimum cut in the topology graph.

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