Augmenting OLSR with Priority Aware Dynamic Routing for Heterogeneous Networking

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Abstract—Optimized Link State Routing (OLSR) has many advantages over other routing protocols for use within MANETs. However, it also has its limitations and cannot easily adapt in real time to the highly dynamic nature of heterogeneous military MANETs. This paper discusses the augmentation of OLSR with a reactive routing algorithm referred to as Priority Aware Dynamic Routing (PADR). PADR along with OLSR forms a hybrid routing approach where routes may be chosen based on metrics that are difficult to account for by proactive routing alone; such as mobility, changing mission needs, dynamic resource allocation, and RF contention. The proposed hybrid approach is designed to operate at the cipher text IP layer and is capable of routing over a single MANET subnet or over multiple heterogeneous subnets.

Keywords—OLSR, MANET routing, heterogeneous routing.

I. INTRODUCTION

Cognitive routing research is focused on optimizing routing based on the spectrum sensing metrics and is intended to optimize over a single homogeneous subnet [1]. In large scale military networks, there is a need for the cipher text IP layer to intelligently route over heterogeneous networks with varied radio characteristics [2]. This paper introduces a stable, priority aware routing algorithm that is used in conjunction with the Optimized Link State Routing (OLSR) protocol to create a hybrid (reactive/proactive) routing technique to optimize routing over heterogeneous networks. The presented technique is referred to as Priority Aware Dynamic Routing (PADR). PADR is built on top of the OLSR protocol, which is standardized and is shown to be suitable for multi-hop routing in Mobile Ad-hoc Network (MANET) environments [3]. However, PADR could also be used in conjunction with other protocols such as OSPF. PADR uses control signaling – Route Requests (RREQ) and Route Responses (RREP) – that is reminiscent of other reactive routing protocols [4], however the hop-by-hop link costing in PADR accounts for the availability of wireless spectrum. This is done by gathering input from a local resource manager that can report the capabilities (bandwidth, latency, availability, etc.) of the available waveforms at each local PADR node. The current implementation of PADR utilizes a resource manager called Organization and Control Proxy (OCP) [5]. OCP is a collection of protocols that provide spectrum allocation and management for a mobile ad-hoc network consisting of heterogeneous waveform technologies. OCP provides the ability to dynamically acquire and release resources in an on-demand fashion to meet the per-link traffic demands. OCP does not select the node used to relay traffic to a given destination; instead OCP manages the waveform resources necessary to relay traffic to a given next hop and supplies PADR with the necessary metrics to create reactive routes. An instantiation of OCP exists over each cipher text IP interface to a collect the corresponding waveform metrics. Note that due to the lack of standardization of military waveforms [2], each waveform could have its own set of link metrics; and OCP has the important job of creating unification at the IP layer so that the waveform specific metrics are translated into route cost.

PADR has many advantages over standard routing protocols including:

1. Its routes are chosen based on factors such as link capability, bandwidth and mobility, which would be difficult to account for with a proactive protocol such as OLSR. The cost of proactively advertising all of this information could be very high for limited bandwidth tactical MANET.

2. Variations in routing metrics do not affect route stability in PADR. Once a route is chosen by PADR it will continue to be used until the link can no longer handle its traffic load. This event – Link Allocation Failure (LAF) – could be a result of link degradation, higher priority traffic preemption or an increase in the traffic demand itself. A LAF event triggers PADR to find another path.

3. User data is only “offloaded” onto PADR routes once bottlenecks manifest themselves on the control routes (OLSR default routes). This decreases the response time inherent in pure reactive routing approaches.

4. PADR was designed and implemented to work with most IP control plane waveforms as well as most offload data links1. This control plane waveform is utilized to efficiently task any available offload data link. Tactical deployment systems often have a low-bandwidth multiple-access wireless media for time-sensitive low-rate traffic in conjunction with higher-rate links (e.g., TDMA based media access, or dedicated point-to-point links).

1 An offload data link is a secondary (usually higher throughput) data link that can be utilized to reduce load on the control network.
5. PADR results in very low overhead when the network is lightly loaded with PADR-qualified (determined by TOS) user traffic or when the dynamics – e.g., node mobility, traffic variability, etc. – of the network are slowly changing so that existing routes are effectively servicing the traffic demand.

6. The hybrid OLSR/PADR allows for different levels of participation. Energy-constrained nodes may either report unfavorable link costs or refrain from running PADR altogether. Such a strategy would prevent the node from being considered for routing higher bandwidth traffic while still maintaining network connectivity as the node would still participate on the control plane.

The implementation of OLSR/PADR allows the user to configure whether a traffic type will use the routes determined by PADR or the route given by OLSR. Specifically, the user’s TOS marking can determine whether or not the packet should be offloaded onto a PADR route (qualified traffic) as well as determine which PADR route table to be used.

II. ADDRESSING BOTTLENECKS AND OSCILLATION

One of the most pressing challenges facing any reactive measurement-based resource management technique is oscillation due to the dynamic nature of MANETs [6]. When routing metrics are derived from currently available link resources, constant changes can cause oscillation as the routing protocol directs traffic to areas of low utilization. Routing oscillation can create unintended bottlenecks and lead to latency and overhead traffic increase as OCP signaling is required to allocate the offload resources.

PADR creates stable routes by:

1. Adhering to the selected route until LAF triggers another route to be acquired.

2. Routing based on destination address and priority (TOS-derived); allows for the distribution of traffic to a particular destination over multiple PADR routes. The resulting destination-priority routes are maintained independently making them immune to the LAF events of lower priority flows.

3. Designating certain traffic types to be “unqualified” for PADR offloading. One candidate for the “unqualified” designation is short-lived and/or bursty traffic; OCP’s offload allocation algorithm is triggered by the average traffic demand so such traffic may cause spurious offload allocations, which could perturb existing allocations. By forcing unqualified traffic to the OLSR paths, the qualified flows are further separated and thus stabilized.\(^2\)

\(^2\) For short-lived flows the OLSR path is likely more desirable as it is the shortest path (if using the hop-count metric for OLSR) and it does not require any setup time.

III. THE BENEFITS OF HYBRID ROUTING

Consider the problem of assigning a relative cost to each of the links A→B and C→D in Figure 1. In the figure the red and black boxes represent a different offload link capability for each node. From the standpoint of the end-to-end flow S\(_1\)→E, the path S\(_1\)→C→D→E would be more desirable than S\(_1\)→A→B→E because the spectrum allocated on link S\(_1\)→A (red offload link) precludes the allocation red offload resources on link A→B, thus reducing the throughput of the flow. By the same reasoning, the S\(_1\)→A→B→E path would be more desirable than S\(_1\)→C→D→E for the S\(_1\)→E end-to-end flow. This demonstrates that optimal link costs cannot be uniformly assigned based solely on the link itself. This observation suggests standard link-state protocols are not applicable for such heterogenous networks. PADR is capable of finding such compatible paths using reactive route probing. A detailed description of this probing mechanism is discussed in Section IV.

Note that creating preference to higher capability nodes may cause bottlenecks at these nodes. Let us refer back to Figure 2. Suppose that node Z is currently sending to node D. Node Z will likely pick node X as its next hop since its metric is relatively small. Next, suppose node S starts sending to node D; the S→W→X→D path is likely to be the more capable route. One can see that such routing configuration could result in many senders directing traffic to a subset of the network nodes (and hence overloading a subset of links) thus overloading the high capability nodes (node X in this case). To mitigate this situation link and/or node utilization is incorporated into the proactive routing protocol’s link metric. The consequence of this approach is that routes may oscillate wildly as the routing protocol directs traffic to areas of low utilization.
resources on each link. Scale network because it takes time to allocate a flow’s situation is especially detrimental when routing over a large network. The PADR participants are aware of the mapping from subnets to their ingress points by way of OLSR’s Host Network Association (HNA) messages. For space considerations we do not discuss this mechanism.

Consider Figure 3, where all links have a fixed capacity of 1Mbps. Suppose the proactive routing protocol uses a link metric dependent on the current link availability. In this scenario node S has a long running flow to node D with bandwidth 100Kbps. Because of the symmetry, the path for this traffic could be either S→W→X→Z→D or S→W→Y→Z→D; suppose the upper path is chosen. Say some time in the future node X sends 100Kbps of traffic to node Z. This raises the link metric and breaks the routing symmetry as far as node S is concerned, so a lower cost path is now S→W→Y→Z→D. If node X stops its flow to node Z and node Y begins sending traffic to node Z, the situation is reversed. Node S’s traffic again would follow the upper path. This situation is especially detrimental when routing over a large scale network because it takes time to allocate a flow’s resources on each link.

PADR avoids this situation by attempting to adhere to routes. Once a route is chosen, it will remain in place until LAF causes another route to be acquired.

IV. PROTOCOL DESCRIPTION

PADR route discovery is initiated by the source of the flow when it receives an Ingress Policing Notification (IP-N). Initially, i.e., before a PADR route has been established, there are no Ingress Policing Limits (IP-L) set so no ingress policing occurs. Such IP-L are set when a node receives a Route Error (RERR) message, specifically by setting IP-L to the RERR.SquelchValue. The RRER is initiated by any node along a traffic path that receives a LAF. Figure 4 illustrates the concept with three flows S1→D1, S2→D2, and S3→D3, all of which are using link j→k.

OCP’s LAF notification includes the current bandwidth available on the link. Upon receiving the LAF, node j’s PADR decides which flows utilizing the link j→k should squelch their traffic to a level that can be serviced. PADR consults its perhaps Traffic Demand Table (TDT) when making this decision. The TDT provides the traffic demand for each next-hop, source, destination and priority. For the example in Figure 4, node j has decided upon a squelch value for each of the S1→D1 and S2→D2 flows and has sent a RERR to S1 and S2. S1→D1’s traffic can still be serviced by the link so there is no need to issue a RERR to S1.

A route discovery – initiated by an IP-N – causes the source node to issue a RREQ whose purpose is to find another path with more bandwidth than the current route’s IP-L. The RREQ is a broadcast message; each node receiving the RREQ will determine the feasibility of the path up to that point and if the path is feasible, the RREQ will be re-broadcast. The RREQ’s path list entry is built up by each node processing the message, so that when the RREQ arrives at the intended destination the path list includes the node identifiers for the entire prospective path.

Figure 5 for an example of the RREQ processing. In this scenario node S has originated a RREQ for the purpose of finding a route to node D (not shown in the figure) and the RREQ is now being processed by node C, having first been relayed by nodes A and B. At this point PADR passes OCP the RREQ path list containing S, A, and B so it can determine the feasibility of the link B→C. OCP makes its determination based on the following factors:

1. The possible offload radio link types for each of the hops (indicated by red and black in the figure).
2. The existing non pre-emptible spectrum allocations for each offload link type.
3. The intra-path interference that would occur if the prospective path is formed.
4. Relative stability of each link; mobility or RF impairments may deem certain links as poor candidates for spectrum allocation.

Figure 3: Example 3, avoiding oscillation.

Figure 4: RERR concept.

Figure 5: RREQ processing.

3 Here “source” refers to the ingress point into the tactical network. The PADR participants are aware of the mapping from subnets to their ingress points by way of OLSR’s Host Network Association (HNA) messages. For space considerations we do not discuss this mechanism.

4 PADR’s resource probing mechanism only supports a single active route discovery at a time; otherwise link costing would need to account for the potential allocations of all outstanding route discoveries. The implementation incorporates a back off algorithm to de-conflict among multiple route discoveries.
Since OCP is aware of node locations in its vicinity and the per-radio link closure requirements [5] [7], it can determine if a flow of required minimum bandwidth could occur on the RREQ path list. For the first example in Figure 5, each of the hops S→A, A→B and B→C only has the “red” radio link capability. Due to the intra-path interference, OCP may decide that the path allocation is not possible; in this case the RREQ would not be re-forwarded. For the second example in the figure, where link B→C has the “black” radio link capability, OCP may find a feasible path allocation. In this case node C’s PADR will re-broadcast the RREQ.

Upon receiving a RREQ, a destination node will send a Route Reply (RREP) unicast back to the last-hop along the path. Upon receiving a RREP, a node will setup a PADR route for the intended destination and then re-send the RREP back along the reverse path until it arrives at the initiator of the RREQ. Upon receiving the RREP, the source node will update its IP-L as indicated by the RREP. If the source continues to receive IP-N (either because it never received an acceptable RREP or the RREP it did receive cannot fully handle its traffic demand), it will periodically re-initiate route discovery.

As long as traffic continues to flow on a PADR route and no IP-N has been received, the PADR route is maintained for each participating node. If the traffic drops below a configurable threshold, the PADR route will revert to its OLSR route. To avoid possible routing loops that can occur as a result of running two independent routing protocols, PADR periodically advertises its PADR routes to each of its neighbors. This periodic advertisement is sent via OCP as OCP can efficiently pack this information in its periodic Spectrum Awareness (SA) messaging.

V. PADR, OCP AND OLSR INTERACTIONS

Figure 6 shows PADR’s interactions with OCP and other IP layer modules. Traffic being handled at the IP layer will first be mapped to the PADR route tables based on its TOS marking. The control route table is maintained by OLSR and is not intended to route TOS marked user traffic handled by PADR. This control route table has the following purposes:

1. Routes all non-qualified traffic with the default route.
2. Provides reachability information for other routing protocols.
3. Helps reduce the chance that the network will be flooded with PADR RREQ packets. PADR leverages the information obtained from OLSR to determine the number of hops to the destination. This involves setting and inspecting the Time-To-Live (TTL) marking of RREQ messages.
4. Sends qualified user traffic before PADR’s routing mechanism is initiated. This reduces the end-to-end delay associated with the reactive component.

Note that OLSR’s algorithm selects a set of Multi-Point Relays (MPRs) for the purpose of relaying routing data. This MPR set effectively forms a backbone of connected nodes. This backbone can be utilized for efficient dissemination of other protocols’ data [3].

As shown in Figure 6, PADR maintains several of its own route tables, one for each priority: (H) for high priority, (M) for medium priority, and (L) for low priority. The separation between different priorities at the routing level allows for different routes between traffic priorities and prevents lower priority traffic from creating bottlenecks and oscillations for higher priority mission critical traffic.

In the figure the following abbreviations are used:

- **IP-N**: Ingress Policing Notifications – PADR receives these notifications when traffic exceeds its current allotment.
- **IP-U**: Ingress Policing Updates – PADR updates ingress policing rates upon receiving a RREP or RRER.
- **MPR-S**: MPR Status – OLSR will notify OCP if it is an MPR [3], OCP can use this information to more efficiently disseminate control traffic.
- **NBW-U**: Neighbor Bandwidth Update – Used by OCP to allocate offload spectrum [5].
- **Res-Q**: Resource Query – PADR sends this message to OCP to determine the feasibility of a path.
- **Rte-U**: Route Updates – Both PADR and OLSR will issue route updates to the IP routing module.
- **RT-x**: Route Table – Here RT-C is the control route table and it is maintained by OLSR. The low, medium and high priority routing tables (RT-L, RT-M, and RT-H) are maintained by PADR.
- **TF-N**: Traffic Forward Notification – The IP routing module will periodically notify PADR of various traffic demands for the purpose of updating the TDT.
VI. COMPARISON WITH EXISTING SYSTEMS

The Wide-band Network Waveform (WNW) is one of the most studied IP tactical waveforms over the last two decades [8]. WNW protocols allocate the spectrum resources as a mix for contention and TDMA slots. WNW protocols include the following properties: cross layer signaling between layers 2 and 3, dynamic resource allocation of TDMA slots, contention slots for control traffic, preference of TDMA links for less time-sensitive traffic, and selective preemption of TDMA slots to help high precedence traffic over low precedence traffic.

There are many advantages to using PADR with OCP and OLSR over a waveform such as WNW, these include:
1. WNW routing is a specific solution for the WNW waveform; PADR is developed as software modules that are reusable for any deployment architecture.
2. WNW cannot accommodate a mix of waveforms. Route preference is within a single MANET and is still considered a homogenous network. OCP and PADR are true heterogeneous protocols that can accommodate other waveform types. OCP is developed using an open architecture with radio agents (one for each radio link). These agents allow OCP to use any number of radios within a node [5].
3. The presented modular solution is in-line with the open architecture recently adapted by the DoD community [9].

Below, we compare PADR to several other approaches to combining routing with lower-level wireless technologies:
1. Alternative Path Routing [10] is an approach to load balancing traffic in ad-hoc networks. APR’s gain is significant with multi channels in comparison with single broadcast channel and the need to tie routing with media access control and power control to maximize APR gain. While [10] presented simulation results with a comparison to wired networks, it did not address the heterogeneous networking challenges as PADR does.

2. The Dynamic Link Exchange Protocol (DLEP) [11] is concerned in the matter in which critical radio information is conveyed to the local router. DLEP assumes that the radio link has been established over the medium under consideration before metrics are communicated. Routing protocols using DLEP cannot make routing decisions unless the radio link is established. PADR takes DLEP capabilities a step further by having the master agent perform proactive sharing of the node’s radio capabilities over a “control plane” even when a radio link has not yet established. This proactive sharing of information can allow performing spectrum/resource de-confliction, link closure estimates, and bandwidth estimates before link establishment which enables PADR to ascertain potential data rates before establishing the link. Reference [2] discussed router-to-radio interface at the tactical edge building on DLEP but has no mention of proactive sharing of information as with PADR.

3. OLSRV2 [12], which is an extension of OLSR, uses Multi-Point Relays (MPRs) to achieve flood reduction and topology reduction but also makes no assumptions about the underlying link layer. OLSR V2 may use link layer notifications when available and applicable. Although OLSRV2 asserts that link metrics may be derived directly from link layer or from other information, it does not cover the use of control plan for proactive sharing of information as with PADR.

4. Other MANET focused approaches such as AOMDV [4] [13] (which is a follow on for AODV -- a single path focused protocol) find multiple paths using 2 stages: (1) A route update rule establishes and maintains multiple loop-free paths at each node, and (2) a distributed protocol finds link-disjoint paths. Both AODV and AOMDV do not use a control plane or proactive knowledge of routes before they are established. These protocols rely on messaging over established links to form routes.

5. An extension of OSPF known as OSPF – MDR [14] uses MANET designated routes and backup routes. All of OSPF - MDR routes rely on LSAs to provide full or partial topology information. Techniques to reduce control traffic include allowing differential Hellos that report only changes in neighbor status. PADR differs radically from OSPF–MDR in that it: (1) Avoids relying solely on LSAs to provide topology information; (2) it ties the MAC layer resource allocation to routing; (3) it uses a control plane to proactively consider a route before radio link is established.

VII. SIMULATION RESULTS

![Figure 7: OPNET scenario: simple ring where all nodes except node 4 have offload data link capabilities](image)

PADR performance can be assessed under varying scenarios and relies on the presence of a control plane waveform which can be used to take advantage of multiple offload data links. For the simulation results in this section, PADR performance was assessed using an OPNET model of a tactical mesh waveform for the control plane and a high speed TDMA point-to-point waveform for higher rate access. Figure 7 presents a simple OPNET scenario to demonstrate the network throughput gains achieved by augmenting OLSR with PADR.
This simulation scenario is depicted in Figure 7 and demonstrates PADRs reactive nature as well as its preference for maintaining routes until a LAF occurs. This scenario consists of two traffic flows: 0→2 and 6→5. Node 1 can support a higher capacity 8Mbps link between nodes 0 and 2. However, when flow 6→5 is transmitting slot allocation must be shared between neighbor nodes, thus reducing node 1’s overall available capacity. The following describes what is happening at each of the time steps in Figure 8:

**T0:** Node 6 begins sending 8Mbps of traffic to node 5

**T1:** Node 0 begins sending 1.4Mbps of traffic to node 2. Initially, the OLSR route 0→1→2 is attempted, however, because node 5 is transmitting to node 6, a LAF occurs causing PADR to find an alternate route.

**T2:** The alternative route 0→3→4→2 is found by PADR and traffic is transitioned to that route.

**T3:** Node 6 stops sending traffic to node 5, thus freeing up node 1’s resources. PADR does not revert back to the shorter 0→1→2 route as the current route is still stable (no change is seen).

**T4:** Node 0 increases its offered data load to 2.8Mbps causing a LAF on 0→3→4→2 route. PADR reactively searches for an alternative route. The alternate 0→1→2 route is found that can support the new throughput and traffic is transitioned to that route.

**T5:** Node 0 decreases its offered down to 600Kbps.

**T6:** Node 6 begins sending 8Mbps of traffic to node 5. No transition occurs because this route can still support both traffic flows.

**T7:** Node 0 increases its offered load to 1.4Mbps causing a LAF. PADR reactively searches for an alternative route.

**T8:** The alternative 0→3→4→2 route is found by PADR and traffic is transitioned to that route.

**T9:** Node 0 stops sending traffic.

**Figure 8:** Traffic sourced by node 0 destined for node 2 over the course of the simulation via alternate routes.

We presented a hybrid proactive/reactive priority aware dynamic routing (PADR) technique for heterogeneous MANETs. This technique is capable of using OLSR for initial network routing, and reactively finds alternate more capable routes based on real time resource availability. PADR has the following benefits over the use of OLSR alone:

1. Increased reliability for mission critical traffic by determining alternate routes for different priority traffic between the same source and destination.

2. Improved throughput through the utilization of more capable routes as opposed to least hop count routes. Routes determination utilizes information such as mobility, waveform capability, and available spectrum.

3. Avoids saturating high capability (advanced) nodes and maintaining network stability by adhering to existing stable routes.

4. Allows for varying levels of participation in the network. Energy-constrained nodes may refrain from using PADR so to not be considered for higher throughput use.

In deployed systems and in simulation, PADR provides more stable and higher throughput routes than the utilization of OLSR alone. We are working on adapting this hybrid routing technique to multicast traffic exploring how multicast routing can benefit from using a hybrid proactive/reactive routing over protocols such as Protocol Independent Multicast (PIM).

**IX. REFERENCES**


