Optimal Anycast Technique for Delay-Sensitive Energy-Constrained Asynchronous Sensor Networks

Er. Jagdish Patil, Er. Pratik Gite, Sanjay Thakur

Abstract*— *In many networks, it is less costly to transmit a packet to any node in a set of neighbors than to one specific neighbor. This observation was previously exploited by opportunistic routing protocols, by using single-path routing metrics to assign to each node a group of candidate relays for a particular destination.

This paper addresses the least-cost anypath routing (LCAR) problem: how to assign a set of candidate relays at each node for a given destination such that the expected cost of forwarding a packet to the destination is minimized. The key is the following tradeoff: on one hand, increasing the number of candidate relays decreases the forwarding cost, but on the other, it increases the likelihood of "veering" away from the shortest-path route. Prior proposals based on single-path routing metrics or geographic coordinates do not explicitly consider this tradeoff, and a s aresult do not always make optimal choices. The LCAR algorithm and its framework are general and an be applied to a variety of networks and cost models. We show how LCAR can incorporate different aspects of underlying coordination protocols, for example a link-layer protocol that randomly selects which receiving node will forward a packet, or the possibility that multiple nodes mistakenly forward a packet.

In either case, the LCAR algorithm finds the optimal choice of candidate relays that takes into account these properties of the link layer.

Finally, we apply LCAR to low-power, low-rate wireless communication and introduce a new wireless link-layer technique to decrease energy transmission costs in conjunction with anypath routing. Simulations show significant reductions in transmission cost to opportunistic routing using single-path metrics. Furthermore LCAR routes are more robust and stable than those based on single-path distances, due to the integrative nature of the LCAR's route cost metric.

Index Terms*— *Ad-hoc, MANET, Cooperative Caching

I. INTRODUCTION

Routing in communication networks has a long history, going all the way back to the shortest-path algorithms proposed in the late 1950s by *Ford* [7], *Bellman1* [6],and *Dijkstra* [1]. These algorithms compute the shortest path between a source-destination pair in a graph, and form the conceptual underpinnings of most routing protocols designed and implemented to this date. In single-path routing, each link has a cost, the cost of a route is defined as the sum of its constituent link costs, and the shortest-path route is naturally the path with lowest cost between a source and destination. Within this framework, the fundamental "unit" of communication is the transmission of a packet from the current node to the next hop in the route; this primitive is called unicast transmission.

Due to its remarkable simplicity and generality, this combined framework of unicast transmission and single-path routes has worked extremely well, starting from the early days of the *ARPANET* [13, 7] all the way to present packet networks. Yet, in recent years, a new class of networks has emerged, where it is not a priori evident that single-path routing and unicast transmission form the best framework for multi-hop, point-to-point communication. This is the class of multi-hop wireless networks, that consist of nodes connected by wireless links, where some node pairs cannot communicate directly and must use other nodes as intermediate relays.

Certainly, it is possible to use single-path routing in a multi-hop wireless network.

At the same time, information and communication theory tell us that new architectures will allow significantly improved performance. For example, recent developments in cooperative communication [1] show how the broadcast and multi-point nature of a wireless network can be exploited to provide spatial diversity [2] in a new way, and how this diversity ultimately can translate into increased throughput or reliability. Unfortunately, the proposed schemes often make assumptions that do not match available technology, such as full-duplex transceivers, hardware that can repeat and amplify an analog signal, or exact and instantaneous knowledge of fading coefficients.

II. MULTIPLE PATH ROUTING

Multiple path routing makes nodes aware of alternative paths between each other. An advantage of awareness of alternative paths is the fast recovery when a node or a link fails[13]. If a node or link fails, the traffic can immediately be sent on an alternative path that does not contain the failed node or link. Another advantage with multiple paths is the possibility of balancing the traffic load.

A multiple path routing mechanism can be node-disjoint or link-disjoint. Node/link- disjoint path means that no node/link is a part of two different paths between the source and the destination. It is possible for a node to have more than one alternative path, but then a new path cannot contain a node (or link) that is a part of any of the other paths.

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Jagdish patil, Computer Engineering Department, R.G.P.V.,Bhopal/ Lord Krishna collage of Technology, Indore, India.

Pratik Gite, Computer Engineering Department, Pacific Academy of Higher Education and Research University, Udaipur, India.

Dr. Sanjay Thakur, Computer Engineering Department, Lord Krishna College of Technology, Indore, India.

Also, there exists braided multipath where an alternative path is a path not containing at least one node or link from the primary path.

III. ANYPATH ROUTING

Anypath routing means that a packet's path is defined while the packet is traversing the network on its way to its destination. Each node has a set of next hop candidates and the node can forward to any of them. Because of the high loss rate and dynamical quality links in wireless mesh networks[5][6], anypath routing is an advantage because the best possible links for each packet can be selected.

In a paper[4] published in 2008, R. Laufer and L. Kleinrock presents an anypath routing mechanism for single channel wireless mesh networks. The paper presents a routing process finding a set of possible next hops, for each destination. When a packet is to be forwarded towards a given destination, the packet is sent multicasted to all nodes in the next hop set. The first node to receive the packet, forwards it on.

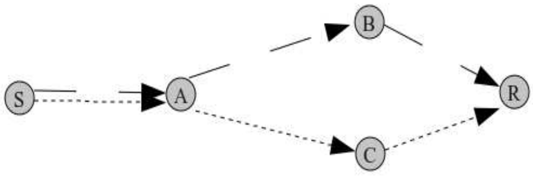

Figure 1: Braided Multipath

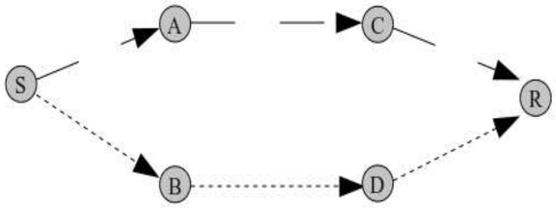

Figure 2: Node Disjoint Multipath

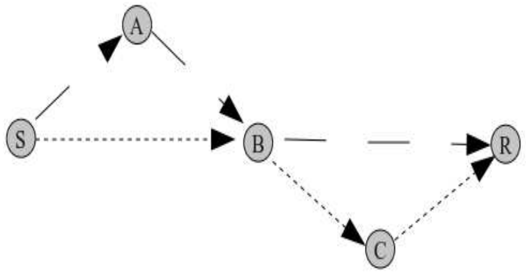

Figure 3: Link Disjoint Multipath

The difference to the anypath routing mechanism presented in this paper, is the usage of multiple channels in this paper as shown in Fig[1], Fig[2] and Fig[3]. Because the next hop candidates may use different channels, multicasting packets to the entire set of possible next hops would introduce a large overhead of switching cost. The anypath mechanism presented in this thesis will not make use of multicasting and so the next hop candidate set will contain only one next hop per channel.

IV. RESEARCH METHODOLOGY

1. Path Cost Calculation

A routing algorithm searches for the best path from a given node to all other nodes within the network. Usually, Dijkstra's algorithm is used, which walks through all paths in the network and finds the best path[7]. The algorithm adds all the costs along the path, to get a total cost for the entire path. An example of costs along the path is the number of hops.

In this thesis, the routing algorithm will consider the delay as the path cost. The costs along the path is the time it takes for a packet to be transmitted over the links and the time the nodes must wait because of switching delays. The cost for each link is estimated by the ETT metric and the switching delay for each node is estimated by the Switching Cost metric.

2. ETT

Expected Transmission Time (ETT) is used to estimate the time it takes for a packet to be transmitted over a link. How the ETT metric value is calculated is described in section

3. SWITCHING COST

Switching Cost (SC) is used to estimate the switching delay for all nodes along the path as shown in Fig[4]. By using the ETT metric alone, the routing algorithm does not result in a fair estimation for the entire path. Only the links' capacity is considered, not the nodes'.

By adding the switching cost to the ETT metric value, the entire time needed for the packet to be received is considered.

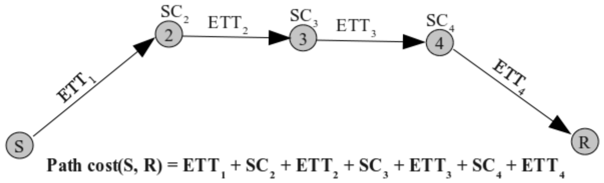

Figure 4

4. Multiple Paths

The decision of whether to store a new found path or not differs between single path routing and multipath routing. When single path routing is used, the routing algorithm must compare a new found path only to a destination with the best path known for the given destination. If the new path has a lower cost than the already known path, the entry in the routing table will be replaced. When the routing algorithm should find multiple paths, where all first hops are using different channels, a new found path must be compared with a possible already known path using the same channel on the first hop.

Figure is showing three different paths from the source node S to the receiving node R, through the next hops A, B and C. The average best path in the example is through the node C with a cost of 8 time units. This path would in a single path routing be the only selected path. In the routing algorithm presented in this thesis, paths using different channels on the first hop will also be considered. Therefore, also the path through the node B will be stored in the routing table. The path through the node A will not be stored in the routing table, because there is another path using the same channel on the first hop with a lower path cost as shown in Fig[5].

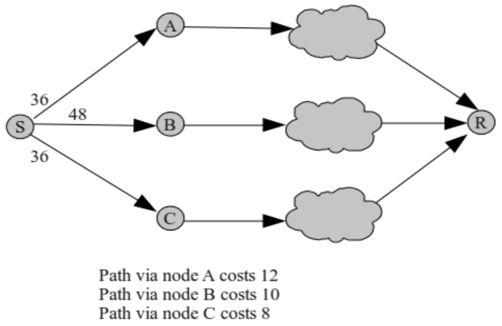

Figure 5

5. Routing Algorithm

The routing algorithm should for each node explore each link to calculate the path cost to the node's neighbors. The path cost is calculated by adding the path cost of the node with the cost of the link to the specific neighbor.

The new path cost is compared with the currently stored path to the neighbor having the same channel on the first hop. If the new path cost is lower than the old path's cost, or if the neighbor's path cost was previously unknown, the new path must be stored. The number of hops must also be calculated, which is done by increasing the previously node's number of hops by one.

6. Routing Table

The routing table needs to be extended for storing the new information from the routing algorithm, multiple paths for each destination and the channel on the first hop. In routing tables of a single path design, there is only one next hop for each destination, which is always used when a packet is to be delivered to a given destination. In the forwarding solution presented in this thesis, a node could have the possibility to forward a packet to a next hop from a set of possible next hops. Therefore, the routing table must be able to store more than one next hop per destination.

When a destination can have several next hops, a forwarding algorithm is needed to select one of them. The forwarding algorithm should select the best next hop for each packet, and therefore it needs information of path cost for the different routes. The channel for the first hop is also needed, so a switch delay can be considered when selecting the next hop. Finally, the number of hops required for each path is needed to prevent loops shown in Fig[6].

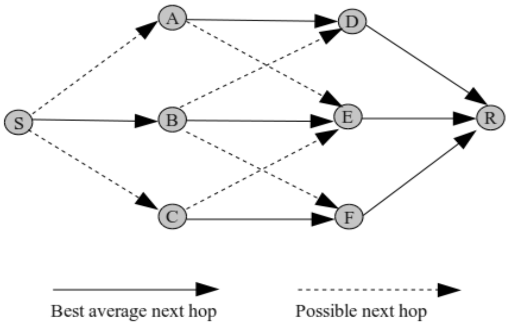

Figure 6: Anypath forwarding

7. Forwarding

In single path routing mechanisms, nodes always forward packets destined for a specific receiver to the same next hop. This next hop is the one that has the lowest average path cost to the receiving node.

The routing mechanism in this thesis forwards the packet to the next hop that is the best for the moment. Due to the changes made in the routing algorithm, a node can have several possible next hops. To decide which next hop that is the best choice for forwarding to for the moment, the total cost for the path must be calculated . The next hop selection considers both the switching delay and the path cost given from the routing algorithm. The switching delay is the time it takes until the required channel can be in use.

The figure shows how the channels are used when traffic is to be sent to a destination, and the node has two neighbors that can both be used as a next hop. Since the single path routing can send on one channel only, it must switch back to channel 36 before it can continue transmitting (the switch to channel 64 is forced by control messages that needs to be broadcasted). When anypath routing is used, the packets can be sent on any of the two channels and therefore it can resume sending earlier.

Before a next hop can be selected, the forwarding algorithm must also consider the number of hops that is required for next hops to reach the destination. This is needed to prevent loops as in Fig[7].

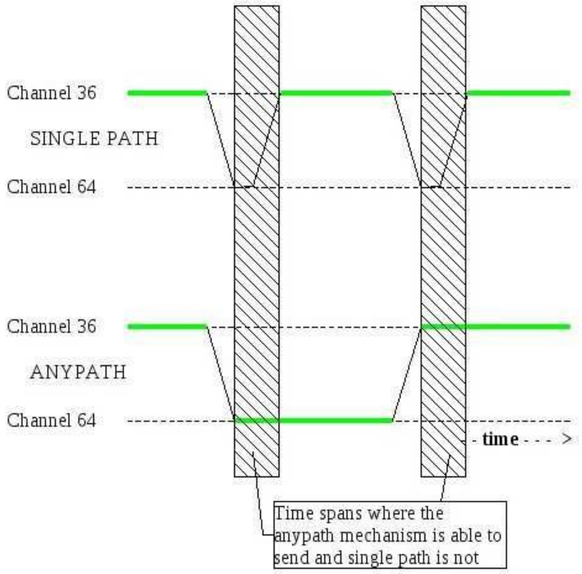

Figure 7

Evaluating Anypath Routing

In this section we describe in more detail our evaluation methodology. We first discuss the protocol mechanisms that are required to implement anypath routing in a practical system, and then describe and motivate our approach to evaluate the performance of anypath routing algorithms.

On Policy vs Mechanism

The core function of an anypath routing protocol is to compute the candidate relay set C(i) at each node i. It is important to emphasize that the choice of CRS C(i) is a policy, as is the effective relay selection (e.g., ERS-best). These policies are carried out in practice using protocol mechanisms, and these mechanisms are (conceptually at least) separate from the policies that they carry out. We now define three key protocol mechanisms that are required to implement anypath routing. Learning link costs and neighbor distances The first mechanism is the one that gathers information necessary to compute anypath routes; that is, the information driving the selection of candidate relay sets at each node using the Bellman-Ford algorithm (5.4). At least two kinds of information must be learned by a node i to compute its candidate relay set: the packet delivery probability pik to each neighbor k, and the estimated distance Dk from each neighbor to the destination. Different techniques exist to estimate the former; a simple example is by means of periodic local broadcasts containing an increasing sequence number allowing a receiver to compute the number of missed packets in a stream.

The distances Dk can be learned also by means of periodic message exchanges, whereby nodes update their neighbors with their current estimated distance to the destination. In addition, a node must learn the distances dij to each neighbor. In most cases, these are either fixed (asynchronous duty cycling) or can be computed from pij (expected transmission count), but in general they can require additional communication, for example to learn schedules with synchronous duty cycling.

Note that such a mechanism for learning link costs and neighbor distances is also required by single-path routing and is therefore not specific to anypath; for this reason we do not discuss it in detail in this paper. However, we can already comment that the cost of periodic message exchanges is proportional to their frequency. A fair comparison between anypath and single-path routing must therefore take into account the frequency at which update messages must be exchanged in either algorithm.

Relay notification

A second protocol mechanism is required to communicate to those nodes in C(i) that they are candidate relays for packets from i, or equivalently, to inform the neighbors not in C(i) that they are not candidate relays.

Definition Relay Notification (RN) is the mechanism used by each node i to inform nodes in C(i) that they are candidate relays for packets forwarded by i toward a given destination.

Similar to the next-hop field in a unicast packet, a simple RN mechanism is for example to add to packets forwarded by i a header listing the nodes of C(i). More sophisticated mechanisms are possible and will be discussed in Paper 7.

Relay arbitration

Just as the candidate relay set of a node must be communicated to that node's neighbors using some protocol mechanism, the effective relay selection policy also requires some protocol machinery. Since a candidate relay node receiving a packet does not know which other nodes may have received it, this node can thus not decide on its own whether or not to become the effective relay (except, of course, in the trivial case that it is the only node in the candidate relay set).

V. CONCLUSION

The goal of this paper was to design and evaluate a novel routing mechanism for multi-radio multi-channel mesh networks following the anypath paradigm. In this paper design for an anypath routing mechanism has been described, and an implementation of the design has been explained.

The test shows that routing mechanism following the anypath paradigm can decrease the end-to-end delay in multi-channel wireless mesh networks. For example, in the simple scenario tested in this thesis, the end-to-end delay was decreased by 22 %. The end-to- end delay can be decreased compared to single path routing due to the possibility for the nodes to have several next hops for each destination. Having more next hop candidates for a destination increases the probability of being able to send without a required channel switch on the sending interface.

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Jagdish patil did his B.Tech in Information Technology Engineering from NMU University, Jalgaon , Maharashtra and Currently Studying M.Tech in Computer Science and Engineering from Lord Krishna College of Technology, Indore , under R.G.P.V. ,Bhopal, Madhya Pradesh(M.P).

His interest areas are in Communication, Network Security.

Pratik Gite He received his Bachelor of Engineering in Computer Science and Engineering from Malwa Institute of Technology, Indore , University of R.G.P.V.,Bhopal in 2009. He currently working as “Assistant Professor” in Lord Krishna College and Technology, Indore .His Pursuing PHD in Faculty of Engineering in Computer Science and Engineering discipline from Pacific University of Higher Education and Research University, Udaipur, Under the Supervision and Guidance of Dr. Sanjay Thakur.

Dr. Sanjay Thakur has completed M.C.A. and Ph.D. (CS) degree from H.S. Gour University, Sagar in 2002 and 2009 respectively. He is presently working as a Lecturer in the Department of Computer Science & Applications in the same University since 2007. He did his doctoral work in the field of Computer Networking and Internet traffic sharing. He has authored and co-authored 30 research papers in National/International journals and conference proceedings. His current research interest is Stochastic Modeling of Switching System of Computer Network and Internet Traffic Sharing Analysis. Email: drsanjay2009@rediffmail.com