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Publication Details

This article was originally published as: Lipman, J, Boustead, P & Chicharo, JF, Reliable optimised flooding in ad hoc networks, Proceedings of the IEEE 6th Circuits and Systems Symposium on Emerging Technologies: Frontiers of Mobile and Wireless Communication, 31 May-2 June 2004, vol 2, 521-524. Copyright IEEE 2004.

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Abstract
Information dissemination (flooding) forms an integral part of routing protocols, network management, service discovery and information collection (sensing). Given the broadcast nature of ad hoc network communications, information dissemination provides a challenging problem. Blind flooding in ad hoc networks results in the broadcast storm problem. To limit the broadcast storm problem, mechanisms for optimised flooding have been proposed. However, this optimisation reduces the inherent level of redundancy. the minimum spanning tree (MST) algorithm using local one hop topology in a distributed manner as the basis of a more reliable optimised flooding mechanism called, reliable minimum spanning tree (RMST) flood is proposed. RMST utilises unique properties of MST graphs that allow for broadcast transmissions to be replaced by unicast transmissions. Unicast transmission is inherently more reliable than broadcast transmission as it utilises link layer acknowledgement and retransmission, thereby improving the reliability of a flood and reducing the broadcast storm problem. Simulation is used to show that RMST is able to achieve equivalent reliability in terms of packet delivery compared to blind flooding. Importantly, RMST is able to achieve significantly better performance than MPR and equivalent performance to LMSTFlood in terms of reducing the broadcast storm problem.

Disciplines
Physical Sciences and Mathematics

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IEEE 6th CAS Symp. on Emerging Technologies: Mobile and Wireless Comm.
Shanghai, China, May 31~June 2, 2004

Reliable Optimised Flooding in Ad hoc Networks

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***Abstract*— Information dissemination (flooding) forms an integral part of routing protocols, network management, service discovery and information collection (sensing). Given the broadcast nature of ad hoc network communications, information dissemination provides a challenging problem. Blind flooding in ad hoc networks results in the broadcast storm problem. To limit the broadcast storm problem, mechanisms for optimised flooding have been proposed. However, this optimisation reduces the inherent level of redundancy. We propose to apply the Minimum Spanning Tree (MST) algorithm using local one hop topology in a distributed manner as the basis of a more reliable optimised flooding mechanism called, Reliable Minimum Spanning Tree (RMST) flood. RMST utilises unique properties of MST graphs that allow for broadcast transmissions to be replaced by unicast transmissions. Unicast transmission is inherently more reliable than broadcast transmission as it utilises link layer acknowledgement and retransmission, thereby improving the reliability of a flood and reducing the broadcast storm problem. We show through simulation that RMST is able to achieve equivalent reliability in terms of packet delivery compared to Blind flooding. Importantly, RMST is able to achieve significantly better performance than MPR and equivalent performance to LMSTFlood in terms of reducing the broadcast storm problem.**

Keywords: Ad hoc Network, Flooding, Broadcasting

I. Introduction

An ad hoc network is a collection of wireless mobile nodes forming a temporary network lacking traditional centralised administration. Mechanisms for information dissemination in ad hoc networks, such as Blind flooding, form an integral part of communication. Blind flooding is seen as a reliable [1] as all nodes participate in rebroadcasting a message at least once. This redundancy provides an inherently high degree of fault tolerance. However, this results in the *Broadcast Storm Problem* [2]. Numerous optimised flooding mechanisms [3][4][5][6][7] have been proposed to limit the broadcast storm problem. However, limiting the broadcast storm problem reduces the inherent redundancy found in Blind flooding making optimised flooding mechanisms less reliable.

We compare the performance of optimised flooding mechanisms and Blind flooding at reliably delivering a message in the presence of increasing background traffic. We show that Blind flooding is remarkably robust and is able to reliably deliver messages, however; it suffers from the broadcast storm problem. Optimised flooding mechanisms aimed at reducing the broadcast storm problem prove to be less reliable in the presence of background traffic than Blind flooding. Optimised flooding mechanisms rely upon selected nodes to rebroadcast messages during a flood. Given the use of unreliable broadcast transmissions in optimised flooding, a problem arises when nodes responsible for rebroadcasting a message do not receive the message. There exists some work on reliable flooding in wireless networks, however much of this work does not relate to ad hoc networks with an IEEE 802.11 MAC. Related reliable flooding mechanisms [8][9][10][11] provide only limited optimisation and require significant overhead to ensure reliability. Some of these mechanisms require that acknowledgements are returned to the source of a flood, however; this is not always necessary depending upon the application. This is particularly so in a typical ad hoc network where the source of a flood may not know of the existence of non local nodes. There also exist mechanisms [10][11][12] that consider changes to the IEEE 802.11 MAC layer. However we do not focus upon the later in this paper.

In ad hoc networks, there exists a need for optimised flooding mechanisms that limit the broadcast storm problem yet provide reliability in terms of packet delivery. In this paper we propose Reliable Minimum Spanning Tree (RMST) flooding. RMST is a reliable and optimised flooding mechanism that benefits from the unique nature of the localised Minimum Spanning Tree (MST) as used in [6][7]. RMST utilises unicast transmission (with link layer acknowledgement and retransmission), which provides a more reliable transport mechanism than broadcast transmission. Reliability is improved at each transmitting node, thus RMST distributes the load of ensuring flood reliability among all nodes. We show that RMST is comparable with existing optimised flooding mechanism at reducing the broadcast storm problem. More importantly, RMST shows comparable reliability, in terms of packet delivery, to Blind flooding and greatly improves upon reliability provided by existing optimised flooding mechanisms in the presence of background traffic.

This paper is organised as follows. Section II explores the use of distributed MST and proposes Reliable Minimum Spanning Tree flooding. Section III provides a performance evaluation based on realistic simulations. Section IV concludes.

II. Proposed Reliable Flooding Mechanism

The Minimum Spanning Tree (MST) graph [13], shown in Figure 1(a), is a connected graph that uses the minimum

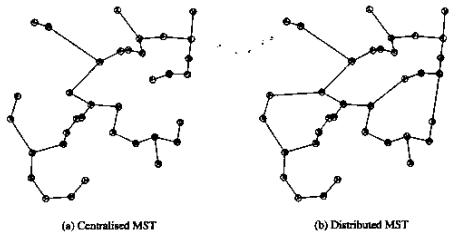

Fig. 1. Centralised and Distributed MST

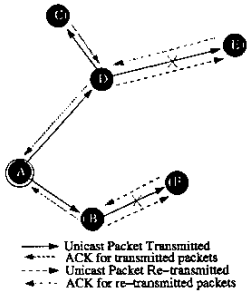

Fig. 2. RMST flood utilising IEEE 802.11 unicast and link layer ARQ

total edge length. This results in a graph with one less edge than the number of vertices. The MST is traditionally used in networks for determining broadcast trees using global topology information. In [6] and [7] the authors propose the use of MST with restricted one hop topology as the basis of a distributed optimised flooding mechanism. This allows for an optimal broadcast set (BSET) of nodes with minimal transmission range to be determined as with the centralised approach. More importantly, the resulting distributed MST graph (Figure 1(b)) does not exhibit the tree like structure of the centralised MST (Figure 1(a)). It can be seen by comparing Figure 1(a) and Figure 1(b) that *centralised MST* $\subseteq$ *distributed MST* as described in [14]. Thus many of the performance benefits (reducing the broadcast storm problem) of centralised MST are maintained with the addition of fault tolerance not found in the centralised MST approach. However, there exists a significant problem in broadcast environments where a broadcast transmission may be lost due to packet corruption, packet collision or hidden node transmissions. Therefore it is possible that nodes may not receive a broadcast transmission. Furthermore those nodes that do not receive a broadcast transmission may be required to receive a transmission. This is especially true in the case of optimised flooding mechanisms, where selected nodes are responsible for retransmission. Given that optimised flooding mechanisms greatly reduce the redundancy found in Blind flooding, there may be situations where a packet may be lost and a flood may not propagate due to reduced redundancy.

RMST is a reliable and optimised flooding mechanism that computes a local MST based upon one hop neighbour knowledge in a distributed manner as is done in [6] and [7]. The MST allows nodes to determine the closest neighbouring nodes that must be included within any transmissions, to ensure a connected graph, thereby ensuring a flood propagates throughout an ad hoc network. The distributed MST results in a connected graph with a neighbour degree greater than one but less than six and an average neighbour degree of less than 2.04 nodes [14]. If the prior broadcasting node is removed, the average neighbour degree is reduced to 1.04 nodes. This low neighbour degree results in a reduced BSET of neighbouring nodes to which a broadcasting node must transmit a message. The resulting small BSET allows for IEEE 802.11 broadcast transmissions (as used by existing flooding mechanisms) to be replaced with IEEE 802.11 unicast transmissions. Unicast transmission is a more reliable transport mechanism than broadcast transmission as it implements a RTS/CTS exchange at the MAC layer prior to transmission in order to reduce problems associated with the hidden node problem. More importantly, unicast transmission utilises a frame retransmission mechanism at the MAC layer based upon a positive acknowledgement scheme (ARQ). Thus, a transmitting node will retransmit a frame if it does not receive a positive acknowledgement from the destination node. The IEEE 802.11 ARQ is not completely reliable and packet loss is still possible. However it provides a more reliable transport mechanism than broadcasting and requires no modifications to the MAC layer. The number of retransmissions before a timeout occurs may be adjusted, but is generally 4-7 retransmissions. If a node fails to retransmit a message to a destination node, it is able to detect the failure and may utilise an alternative scheme (such as broadcasting) to continue dissemination.

Figure 2 shows the distributed MST graph for a topology of nodes. Nodes obtain their local topology through the exchange of beacon messages. Nodes B and D are node A's determined MST neighbours and must be included in any transmissions from node A. In LMSTFlood, node A would adjust its broadcast transmission power to include the distance of its furthest MST neighbour. However, in RMST, node A will first unicast a message to its furthest MST neighbour. The unicast is shown by a black directed line. If this unicast is successfull it will then unicast the message to the next furthest node, in this case node B. The reasoning for unicasting to the furthest node is a result of the limited transmission distance and the possibility of a node moving out of broadcast distance in a highly mobile environment. In Figure 2, both unicast messages are successfully delivered. However, when node B transmits to node F and node D transmits to node E both packets are lost or corrupted. Therefore, at the link layer, both nodes then retransmit as shown by the dashed grey directed lines until an ACK is received or the maximum number of retransmissions is reached.

Each node, upon receiving a broadcast message, calls *RMST(message)*. The algorithm determines if the message has been seen before. If not, then a BSET is determined by supplying the MST with the node's one hop topology. The previous broadcasting node and all neighbouring nodes that may have heard the previous broadcast are removed

from the BSET. If the BSET is not an emptyset, then the required transmission power to reach the remaining nodes in the BSET is determined and the message rebroadcast. The MST algorithm used is based upon Prim's algorithm [15].

Algorithm *RMST(message)*

```
if not seen message before
        BSET ← MST(1-hop Neighbours)
        i ←previous broadcasting node
        H ←nodes that recieved previous broadcast
        BSET ← BSET − i
        BSET ← BSET − H
        for each node i in BSET
                T_power ← transmission_power(i)
                Unicast(Message, T_power)
```

III. Results

We utilise the GloMoSIM 2.03 simulation environment with two different MAC layers. An ideal NULL MAC layer is used to create an environment with no medium contention nor hidden-node scenario. The transmission medium is error free. A bidirectional link between two nodes is assumed upon reception of a beacon message. In the NULL MAC layer, a first order radio model [16] is assumed. In this model the first order radio dissipates $E_{elec} = 50nJ/bit$ to run the circuitry of a transmitter or receiver and a further $E_{amp} = 100pJ/(bit*m^2)$ for the transmitter amplifier. Equation 1 is used to calculate the costs of transmitting a k-bit message a distance d. Equation 2 is used to calculate the costs of receiving a k-bit message. The radios have power control and consume the minimal required energy to reach the intended recipients. The second MAC layer tested is the IEEE 802.11 MAC layer as implemented in GloMoSIM, however this has been modified to allow transmission power control for broadcast and unicast packet transmission as required. The simulation area is 600 meters by 600 meters. Nodes are placed in a random topology within this area. Nodes have a maximum transmission range of 100 meters. A node within each random topology is selected randomly as the source of a flood. The topologies generated are not fully connected thus some topologies may result in a partitioned ad hoc network. The total number of nodes reachable for each topology is determined so as to account for partitioning.

$$E_{Tx}(k,d) = E_{elec} * k + E_{amp} * k * d^2 \quad (1)$$

$$E_{Rx}(k) = E_{elec} * k \quad (2)$$

Simulations are run 50 times with a different seed for each run. The final results are averaged and 95% confidence intervals are displayed in each graph. Blind flooding, MPR (source based) and LMSTFlood are the comparison flooding mechanisms. Blind flooding is selected as it is a brute force approach with a high degree of reliability, but suffers from the broadcast storm problem. MPR and LMSTFlood were selected as they are both optimised flooding mechanisms that reduce the broadcast storm problem in ad hoc networks. LMSTFlood utilises transmission power control thus limiting the number of nodes affected by a broadcast, whereas MPR does not.

Figure 3 shows the percentage of nodes that receive a message as the CBR packet rate is increased. In a NULL MAC environment, delivery is assumed to be 100%. However, in GloMoSim the use of a more realistic IEEE 802.11 MAC and transmission medium, results in packets being lost due to collision, corruption and fading. We utilise three CBR source-destination pairs in the simulation to create background traffic that may effect the delivery performance of the flooding mechanisms. The source-destination pairs are selected randomly and UDP packets of 512 bytes are transmitted between nodes using the AODV routing protocol. Each source begins transmitting data at a random time prior to the initiation of a flood.

From Figure 3, it can be seen that Blind flooding and RMST provide the best delivery performance and are only slightly affected by background traffic. Blind flooding provides reliability through redundant broadcasts, but suffers from the broadcast storm problem as shown in Figures 4 - 6. However, RMST being optimised limits the broadcast storm problem. RMST achieves comparable delivery to Blind flooding as it utilises unicast transmissions which are more reliable than broadcast transmissions. LMSTFlood and MPR suffer in delivery as broadcast packets are affected more significantly by background traffic as both mechanisms rely upon specific nodes receiving a broadcast. In the case of LMSTFlood, nodes are able to determine whether they are required to rebroadcast by calculating their local MST. But if a node does not receive a broadcast message then it effectively halts the flood in that direction. MPR (source based) attaches a relay list to the broadcast message, thus if the message is not received by one or more of the relays, then it may effectively cancel the propagation of the flood at that point.

Figure 4 shows the power consumed by each mechanism to complete a flood. RMST utilises more energy to complete a flood than LMSTflood. This is expected as RMST must perform more transmissions (Figure 5) than LMSTFlood, resulting in more duplicate packets (Figure 6). Compared to Blind flooding and MPR, RMST shows significantly better performance in terms of reducing the broadcast storm problem. The use of transmission power control in RMST when unicasting allows for a reduction in duplicate packets received and limits the number of nodes that will hear a transmission thereby reducing power consumption.

Thus, the combined use of unicast transmission and distributed minimum spanning tree enables RMST to achieve comparable reliability to Blind flooding, surpassing existing optimised flooding mechanisms. Additionally, RMST effectively limits the broadcast storm problem outperforming MPR and acheiving comparable performance to LMSTFlood.

IV. Conclusions

Various mechanisms for reliable flooding have been proposed in literature. However, they either suffer from significant overhead to disseminate and determine if a flooded message

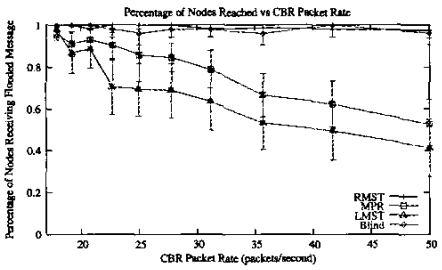

Fig. 3. Broadcast Reachability with Background CBR traffic

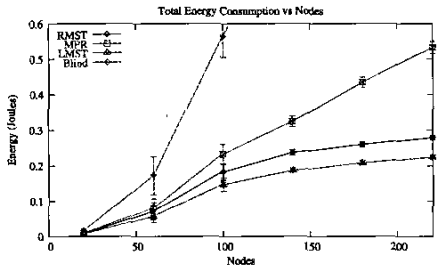

Fig. 4. Energy consumed

was received or they require modifications to the IEEE 802.11 MAC layer to improve broadcast delivery between nodes. In this paper, we have introduced Reliable Minimum Spanning Tree (RMST) flooding. RMST is a distributed and more reliable optimised flooding mechanism that benefits from the unique nature of the distributed minimum spanning tree and requires no modification to the IEEE 802.11 MAC layer. RMST utilises unicast packet transmission, which provides a more reliable transport mechanism than broadcast packet transmission as used by existing optimised flooding mechanisms. We show that RMST compared to LMSTFlood, MPR and Blind flooding is able to reliably deliver packets given three source-destination pairs generating CBR traffic. In fact the performance of existing optimised flooding mechanisms was shown to suffer in the presence of CBR traffic as packet rate was increased. RMST shows comparable performance at reducing the broadcast storm problem when compared to existing optimised flooding mechanisms. Significantly, RMST shows equivalent packet delivery performance when compared

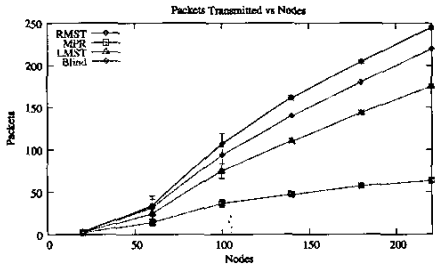

Fig. 5. Packets transmitted

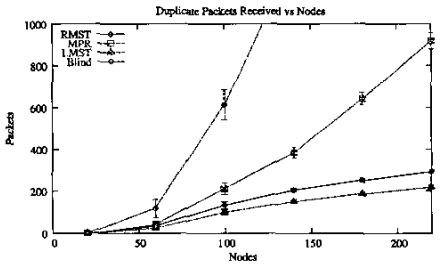

Fig. 6. Duplicate Packets Recieved

to Blind flooding.

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