Interference-Aware Geocasting for VANET

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***Abstract*—With the introduction of standards such as DSRC and WAVE, vehicular ad hoc networks (VANET) are being considered as candidates to improve road safety. Safety applications developed on top of VANET enable vehicle and driver improved awareness of the road situation through vehicles sharing their status and knowledge of the road conditions. In order for these systems to operate, they depend on reliable communication. To overcome fading, shadowing and other effects that cause packet loss, such applications commonly use retransmission schemes to improve packet delivery. However, the wireless channels used for these applications are bandwidth constrained, and retransmission can cause interference which in turn will degrade the reliability of the communication channel. Therefore, it is necessary to find a strategy that balances retransmission with channel occupancy for optimal reliability.**

In this paper, we present a cooperative retransmission algorithm that overcomes shadowing caused by blocking objects such as heavy vehicles in order to combat the resulting unreliability, whilst controlling the interference caused by retransmissions. The proposed algorithm weighs up the additional area a node can cover, with the amount of interference a retransmission by the same node would cause. We evaluate the performance of the algorithm in urban scenarios using the NS-3 simulator, and find that the proposed algorithm is effective in overcoming the negative effects of shadows caused by blocking objects.

I. Introduction

Vehicular ad-hoc networks (VANETs) have been proposed as a safety tool for vehicular traffic. A VANET is a network consisting of many highly mobile, wirelessly connected nodes, mounted on vehicles and road infrastructure. VANETs enable vehicles to communicate directly with each other and the road infrastructure, and can therefore be used to improve road safety by enabling exchange of information. Systems such as cooperative collision avoidance (CCA) [1] and cooperative collision warning (CCW) [2] use VANETs to exchange safety messages in order to improve road safety. These proposed systems operate on a control channel which has limited capacity, thus repeated and irrelevant messages need to be minimised to avoid unnecessary contention.

Being wireless communication systems, VANETs are exposed to many effects that can limit their communication reliability, and therefore limiting the reliability of any safety systems based on them. Since VANET nodes are highly mobile, they may at times experience significant multipath fading (*e.g.* in tunnels and car parks) and shadowing (*e.g.* behind a heavy vehicle).

Previous experiments and simulations [2], [3] have identified that a large proportion of transmitted packets are lost due to fading [3], even when the receiver is as close to the transmitter as half the maximum transmission radius. In addition, obstructions between the transmitter and the receiver can further attenuate the signal, thus decreasing the reliability of the system.

It is well known that heavy vehicles cause shadowing in radio channels. Radio channel measurements and analyses conducted in the 1990's [4] showed that large vehicles can cast a deep shadow between 6dB and 30dB at 900MHz in an experiment that measure signal strength across the width of a tunnel. Since DSRC operates at 5.9GHz, and electromagnetic fields do not diffract as much at this higher frequency, one can expect an attenuation of at least that magnitude.

In order to combat packet loss resulting from this shadowing effect, hence increasing the robustness of VANET transmissions, we present an interference-aware, cooperative geocast packet retransmission algorithm. Using this algorithm, each node independently makes the decision of whether to rebroadcast a received packet based on an estimate of the amount of interference generated by the node if it retransmits the packet, as well as the expected additional node coverage. This algorithm is evaluated through simulations using the NS-3 network simulator.

The rest of this paper is structured as follows. Section II reviews the relevant literature, then the proposed algorithm and metric is presented in Section III. Section IV outlines the evaluation of the algorithm by simulation, with the results presented in Section V. Section VI then discusses aspects of the algorithm and evaluation before drawing conclusions in Section VII.

II. Related Work

Methods to improve packet reception ratio include both localised strategies that operate on the sender, as well as cooperative retransmission strategies. Localised strategies include QoS-based techniques [3] and repetition techniques [1], and tend to generate lower interference. QoS-based techniques work by giving priority to emergency traffic, thus reducing the channel contention for this class of traffic. Repetition techniques improve packet reception by adding temporal redundancy, thus help overcome fast fading and packet collisions. However both QoS and repetition techniques are ineffective for mitigating packet losses due to shadowing [1].

Cooperative retransmission exploits the broadcast nature of wireless communication to provide spatial diversity. Currently, many cooperative retransmission schemes have been designed to route unicast packets in a wireless ad hoc or mesh network

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so as to minimise the number of retransmissions and/or latency. Some of these strategies have also been adapted for broadcast and geocast. Examples of these strategies include the retransmission algorithm presented by Briesemeister [5] and M-GeRaF [6].

Many cooperative retransmission strategies used in geographical routing and VANETs either require an *apriori* knowledge of the network topology [7], [8] or tend to generate interference outside the coverage area [5], [6]. Methods using *apriori* knowledge need accurate and current knowledge in order to decide the forwarding nodes, and therefore introduce higher overhead to maintain this knowledge. These methods also minimise overall interference by carefully selecting forwarding nodes. By selecting specific nodes for retransmission, transmission errors to the forwarding nodes may result in many nodes not receiving data successfully.

On the other hand, schemes that assume no knowledge of topologies [5] can use only local knowledge to make forwarding decisions. Since nodes do not coordinate amongst each other, the transmission might be triggered at suboptimal locations, causing nodes to receive duplicate and/or irrelevant packets, thus generating a larger amount of interference both within and outside the coverage area. This interference reduces the capacity of the network both by taking up air time as well as causing collisions with other transmissions. When broadcast messages are infrequent, these schemes can function relatively well, but they may not be able to handle the high broadcast loads as expected from Cooperative Collision Avoidance Systems.

III. Packet Retransmission Scheme

To address the interference problems inherent in cooperative retransmission schemes that assume no *apriori* knowledge of the network, we propose a scheme that aims to maximise the gain in coverage area while minimising the interference caused. Similar to the schemes above, the proposed scheme exploits spatial diversity, enabling nodes that were unable to receive a packet due to shadowing to receive a forwarded copy from another node. Instead of using *apriori* knowledge of the network to minimise interference (which introduces overhead in establishing and maintaining this knowledge), the scheme makes retransmission decisions based on a metric that takes into account the ratio between benefit and cost, *i.e.* additional coverage-to-interference ratio. Unlike the greedy algorithm in [5], which uses node distance as the metric thus optimises hop count but often generates large interference outside the required area, the cost-benefit metric not only can reduce the interference to the outside, but will also naturally choose the furthest node if needed. In this paper, we define a node as experiencing interference if its radio interface senses the channel to be busy, or when receiving duplicate and/or irrelevant packets.

In this scheme, we represent the required coverage area of a packet by a unit disc, with the centre and radius specified in the packet header. The header contains an expiry field, which limits the extent of flooding by preventing the retransmission of stale packets. While the packet itself does not contain any history of whether or by whom the packet has been forwarded, each node may keep track of its received packets.

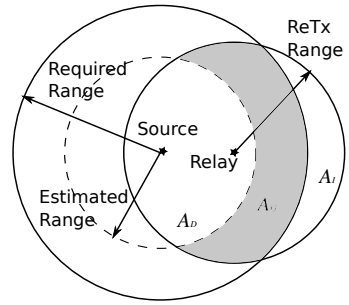

Fig. 1. Derivation of Metric — Required range is specified in the packet header; Estimated range is determined based on packet received signal strength; ReTx range is based on transmit power; A_D is the area receiving duplicate packets; A_G is the area additional coverage due to retransmission; and A_I is the area unnecessarily receiving the packet

A. Retransmission Metric

The proposed retransmission metric is based on the ratio of the area of additional coverage ("gain") to the area of interference, and is evaluated by considering the geometry of overlapping coverage areas. To simplify the metric, we assume unit-disc propagation, and uniformly distributed nodes. Figure 1 is a graphical representation of this geometry. Since the exact values of these areas can be computed using simple circle geometry [9], formulas for computing these values are omitted from this paper. Using these areas the metric for retransmission decision can be easily calculated as the ratio of the area benefited to the areas receiving interference:

$$M = \frac{X A_G}{A_D + A_I} \tag{1}$$

Here, X is a configurable parameter related to the tolerance of interference. X can be any positive real number, with higher X showing a higher tolerance to interference (nodes are allowed to interfere more.) Retransmissions can be turned off by setting X to 0, and if X is very large, all nodes will always retransmit. Using this metric, nodes with higher M is better positioned to retransmit the packet because they have a better coverage-to-interference ratio.

In the proposed implementation of this scheme, nodes estimate the range of each received packet (new or retransmitted) using the received signal strength. By assuming that the packet was sent from the centre of the circle and all attenuation was due to path loss, the areas above can be calculated.

B. Retransmission Algorithm

To prioritise nodes for retransmission, a delay-based algorithm is used similar to the prioritising scheme in M_GeRaF [6]. M_GeRaF is a geographic multicasting scheme that prioritises potential relays based on the direction change required to forward a packet. Once a packet is received and forwarded up the MAC layer, a retransmission delay is calculated based on

TABLE I
RETRANSMISSION ALGORITHM

```
receive_packet(pkt):
  if pkt has never been seen:
    Pass pkt to higher layer
  if a version of pkt (pkt') is in Tx queue:
    Estimate range of pkt based on received signal strength
    if pkt can propagate further than pkt':
      Drop pkt' from the Tx queue.
    else:
      Ignore pkt and return
  if pkt has never been seen or pkt' was dropped:
    M = calculate_metric()
    t_delay = calculate_delay(M)
    if pkt is not yet expired after t_delay:
      Add pkt to transmission queue with delay = t_delay
```

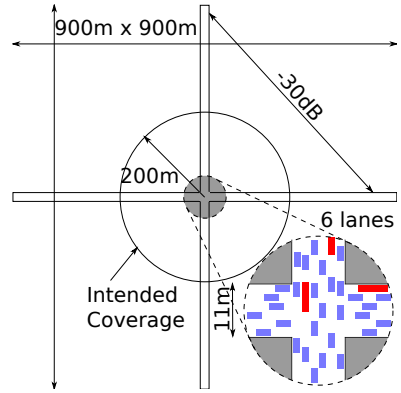

Fig. 2. Vehicle layout — Tagged sender at centre of circle

the retransmission metric (M) using (2). This function maps M to a delay such that delays for high M (highly desirable node) tends to 0. T_{pkt} is the maximum lifetime of a packet thus disabling retransmissions for $M < 1$, which represents the situation where the area ratio is below the minimum specified. To avoid unnecessary transmissions, packets are not added to the transmission queue if the calculated delay means that the packet will be transmitted after it has expired. A packet will be retransmitted after the calculated delay if a copy of the same packet with a higher received signal strength (hence can propagate further) was not received during the delay period. If a copy of the packet with a higher received signal strength was received during the delay period, the packet is dropped from the retransmission queue, and the new copy of the packet will go through the retransmission algorithm to determine a new delay. Table I outlines the proposed retransmission algorithm.

$$delay = \frac{T_{pkt}}{M} \tag{2}$$

For simplicity of implementation in the evaluation, the retransmission algorithm is independent of the MAC and link-layer mechanisms. When the algorithm "retransmits" the packet, it sends the packet down to the link layer. The packet is then subjected to the normal MAC delays (back off, IFS, *etc*). This algorithm does not use the 802.11e mechanism for prioritising packets. Implementation of this algorithm above the MAC layer without cross-layer notification of MAC state changes can cause clustering of delayed packets — many packets with different delay values may be submitted to the MAC transmit queue during the reception of a packet, and the algorithm is unable to remove packets currently in the MAC transmit queue. This clustering can overflow the MAC queue and can greatly increase the contention on the channel. A production- grade implementation would benefit from being advised of state changes at the MAC layer (thus able to pause the delay timer when channel is busy), and should be able to drop packets from the MAC transmit queue.

IV. PERFORMANCE EVALUATION

We evaluated our proposed algorithm using the network simulator NS-3.9. In the simulation, the vehicles are arranged in two intersecting, 900m long, 6-lane road segments (3 lanes each way for each road segment). Since the required coverage area is a 200m radius circle at the centre of the field, and the maximum transmission range of each vehicle is at most 200m; this field is sufficiently large to capture all expected interference and to avoid edge effects. Given node mobility is negligible for the duration of the short VANET safety messages, we can safely approximate the network as a static topology to avoid the ripple effects caused by nodes entering and leaving the coverage area during a simulation.

Vehicles in the simulation are distributed linearly along each lane, with the spacing between consecutive vehicles following a Poisson distribution. This produces lanes of vehicles with specific vehicle density. In cases where two vehicles overlaps each other, their positions are adjusted to the minimum vehicle separation. Two types of vehicles are modelled: cars (5.5m×2.5m, no shadows) and heavy vehicles (12m×2.5m, attenuates all packets that travels into/out of/across it by 20dB). All nodes in these scenario generates beacon packets at 10Hz. Figure 2 shows a typical vehicle layout.

The propagation models used in this simulation are the log-distance path loss model combined with the Nakagami fast fading model as well as the vehicle shadowing model described above. Table II details the parameters for the simulation. A 10MHz OFDM channel was used for the PHY model, under an NQoS 802.11 MAC layer. The application modelled transmits raw MAC frames, no management algorithms for any layer above MAC except for the retransmission algorithm under test are active on the nodes. The 802.11 model used does not account for the packet capture effect, which is non-standard but is present in many chipsets.

The simulations were performed with all nodes transmitting regularly, approximating the intended use-case of Cooperative Collision Avoidance (CCA) systems. Even though all nodes transmits packets we track only the packets generated by one tagged node at the centre of the intersection. 10 vehicle layouts are generated for each node density setting. For each layout, background beacons are generated at 10pkt/s (as proposed for many VANET applications), and a sample of 20 tagged packets are taken for each algorithm under test. The

TABLE II
SIMULATION PARAMETERS

Antenna Gain (Tx and Rx)	2.512dB
Rx Threshold	-95dBm
CS Threshold	-99dBm
Log-Distant Exponent (γ)	2.0
Log-Distant Ref Loss (at 1m)	-47.8588dB (Friis loss, 5.9GHz)
Nakagami parameter (m)	5.0
Attenuation across HV	-20dB
Building Shadow	-30dB
Vehicle densities	{10, 50, 75, 100} veh/km/lane
Proportion of HV	10%
Max transmission range	{50, 100, 150, 200}m
Transmission rate	6Mbps
Transmission bandwidth	10MHz
SIFS	32μs
Slot Time	13μs
Packet Rate	10Hz
Packet lifetime	100ms
Packet size	54 octets (incl. all headers)
Metric param X	0.5, 1, 2, 3, ..., 10

performance measures taken include the proportion of tagged packets successfully received before expiry and relevant to the receiving node, and the time the channel is sensed busy by each node. A range of transmission powers were also tested for each layout.

We investigated the behaviour of our algorithms and compared with well-known approaches that have different strengths and weaknesses. AFR-CS [1] was the initial strategy proposed when the issue of reception ratio was first highlighted and represents a baseline mechanism. In AFR-CS, the sender resends each packet k times in order to combat fast fading. Furthest successful node [5] represents a greedy algorithm which is commonly used for geographical routing in general. A scheme where only heavy vehicles retransmit was also evaluated as shadows in our scenario were cast by heavy vehicles and buildings. Comparing our algorithm with these casts wide spectrum light on the performance of our approach.

V. RESULTS

We evaluate two performance metrics — packet reception ratio (PRR) and channel busy time (CBT). PRR is the fraction of tagged packets transmitted by the sender that were correctly received before packet expiry. It is aggregated over the nodes within the required coverage area. A packet is considered correctly received if at least one copy of the packet (original or retransmitted) is received. CBT is the total amount of time a node's radio interface is either transmitting, receiving or has sensed the channel as busy. CBT is also aggregated over nodes within the coverage area to minimise edge effects. In the figures, CBT is displayed as a percentage of the total lifetime of the tagged packets (100ms $\times$ 20 packets $=$ 2s). The simulations terminate after 2000ms, when all packets not yet received will be expired.

Figures 3a and 3b show the overall PRR and CBT across the different vehicle layouts with the ratio of maximum transmission range to required radius (S) equals to one. These scenarios represent the cases where, in the absence of fast fading, shadowing, collision and without retransmissions, all vehicles within the coverage area should receive all the packets and no vehicle outside the area should receive any packets. Figures 3c and 3d show the performance when S is 0.5, which is a multi-hop broadcast scenario.

As expected, increases in vehicle density cause the PRR to decrease in the no-retransmission case (Figures 3a, 3c), due to the increased number of heavy vehicles between the sender and receiver. PRR is slightly improved when using AFR-CS [1], which overcomes fast fading but not the shadowing caused by the heavy vehicles. As the vehicle density increases, the improvements due to AFR-CS diminishes as more packets are lost due to shadowing (which AFR-CS cannot overcome) than fast fading.

Amongst the cooperative retransmission schemes, it is observed that both the heavy vehicle-only scheme ("HV") and the furthest successful node scheme ("Furthest") [5] are effective at low vehicle densities. HV is effective because heavy vehicles themselves is a major cause of packet loss through radio shadowing when S = 1; whilst at S = 0.5, the proportion of heavy vehicles (10%) in the simulation still provided sufficient forwarders. The furthest successful node algorithm is the most effective at low vehicle densities, due to very low channel contentions and it triggering at least one retransmission for every transmission and their retransmissions until packet expiry.

As node densities increase (even slightly from 10–50 vehicles/km/lane), it can be seen that both the heavy vehicle-only and the furthest-node schemes cause packets to not be received at all. This indicates that these schemes are actually detrimental to packet reception as the density scales up. By observing the channel busy time (fig 3b and 3d), we infer that these algorithms causes too much interference, either by triggering too many retransmissions or triggering them at suboptimal locations.

Figure 3b shows the interference caused by the various retransmission schemes as measured by the channel busy time. As the node densities increases, it can be seen that the CBT for the no-retransmission case also increases due to the increased load (each node transmits 10 packets per second). It is noted that the increase is not linear — higher density increases the probability that two nodes would pick the same back off slot to transmit, and therefore increases the severity of the hidden node problem.

Both the heavy vehicle-only and the furthest successful node schemes causes an approximately 7-fold increase in CBT, even in the lowest density scenario (*i.e.* each packet is retransmitted at least 7 times.) This is unsustainable, and results in an unacceptable amount of packet collisions and lengthening the MAC queue delays, causing packets to expire at higher densities. The "Saturation" line marks the theoretical maximum utilisation for packet duration = 220μs and DIFS = 58μs — the CBT for these schemes approaches and even exceeded the max utilisation at densities higher than 50 nodes/km/lane. Utilisation in excess of the theoretical maximum can occur

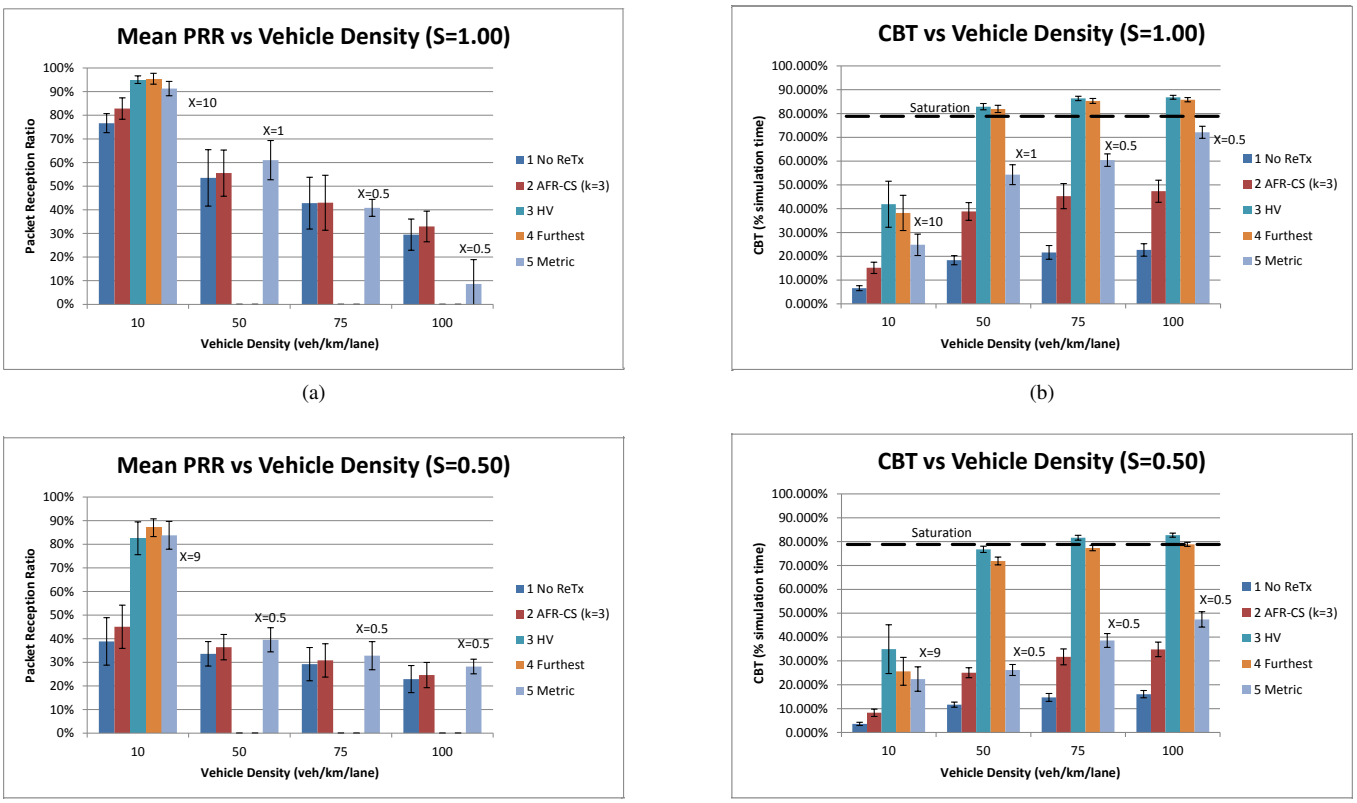

Fig. 3. Results centre-of-intersection scenario, all nodes transmitting (error bars represents one standard deviation), S is the ratio of the maximum transmission range to required coverage radius, saturation marks the theoretical maximum utilisation. Parameter X for the metric cases are chosen to give the best PRR and is common only between corresponding columns in the PRR and CBT graphs. (a) packet reception ratio for $S = 1.00$; (b) channel busy time for $S = 1.00$; (c) packet reception ratio for $S = 0.50$; (d) channel busy time for $S = 0.50$;

due to the hidden node problem.

These figures compare the proposed schemes with the above algorithms. It is important to note that the graphs show the results of the algorithm when configured with parameter X chosen to give the best PRR at that vehicle density. In terms of PRR, the results show that the proposed algorithm provides some improvement over AFR-CS at lower vehicle densities. At high density, the algorithm still performed poorer than AFR-CS, but the degradation is slower than the other cooperative schemes due to its lower interference.

Figures 3c and 3d show the benefit of the algorithm in terms of spatial diversity. These results correspond to the case where the source can only reach half it's required radius, hence AFC-CS is ineffective in providing improvement. Here, the furthest successful node algorithm provides the best PRR in low node densities because this is the situation it was designed for. The proposed algorithm is also able to produce the multi-hop behaviour in these situations, as evident by the high PRR at low vehicle density. In addition, the lower interference it generates enabled it to degrade slower than the other cooperative schemes (it even provided better PRR over AFR-CS at 100 vehicles/km/lane) whilst the furthest successful node scheme quickly saturated the channel, causing packets to not be received at all.

VI. Discussions and Future Work

A. Behaviours and limitations of the algorithm

Using the metric presented, the proposed algorithm optimises the proportion of additional coverage at each retransmission. The parameter X was introduced in order to prevent poorly located nodes to even attempt to retransmit. Under certain conditions, the proposed non-range adapted scheme will behave similar to some common algorithms:

- As X approaches 0, retransmission is discouraged, and the algorithm will not retransmit when X is 0;
- As X increases, retransmissions are encouraged while the delays between nodes of different priority are reduced. As X approaches infinity, the algorithm becomes "Always retransmit immediately";
- As maximum transmission range reduces past half of the required radius, the optimal location moves towards the edge of the transmission range (no risk of interfering outside the required area). The algorithm then behaves similar to the furthest-node algorithm;
- As the maximum transmission range approaches the required radius, the optimal location moves towards the centre of the coverage area. For very high node densities, the algorithm approximates the AFR-CS algorithm (ex-

cept the retransmission is made by a node very close to the source instead of the source itself).

This flexibility allows the algorithm to adapt its behaviour as the situation dictates.

On the other hand, the metric assumes log-distance path loss as the only cause of signal attenuation. This simplified the calculation of coverage-vs-interference, but in reality, the coverage-vs-interference can be very different to the calculated value. Consider the case where an obstruction completely blocked transmissions in certain directions from a node but leave some paths unattenuated (*e.g.* at an intersection with a building that casts very deep shadow), the nodes that are required to forward the message will not be triggered to retransmit as they cannot measure any unexpected attenuation.

In addition, the algorithm uses a maximum interference tolerance (X) to limit the number of retransmissions. This has the side effect that the algorithm cannot guarantee 100% packet reception even in perfect conditions because the ratio of coverage-vs-interference will approach 0 as the original packet estimation approaches the required radius ("law of diminishing returns"). This means that for any chosen X, there will always be some "critical" estimated range, above which retransmission will not occur even if all nodes know the packet will not be received by all intended recipients.

B. Determining parameter X

To provide the performance, the simulation results showed that X needs to be varied as node density changes. The choice of parameter X is essential for the correct function of the algorithm. A low X discourages retransmissions except when it is highly advantageous (preferable for high vehicle densities), and will not retransmit at all when X is 0. A high X allows more nodes to retransmit, but will also reduces the effectiveness of the priority scheme, increasing the potential for collision (may be required for very low vehicle densities).

Future work on this algorithm will include finding a suitable formula to determine the parameter X based on the node's current condition. One can either use node density (or the number of neighbours) to determine X, or alternatively, a reactive strategy that estimate the local channel contention and moderates X as required may also suffice. Heusse *et al* [10] presented a technique whereby MAC contention is moderated based on observed idle slots. While this technique can improve packet reception and throughput for delay-tolerant messages, it is not useful for adjusting the load given to the MAC layer. We are investigating a scheme that moderates X based on the observed idle slot count.

C. Excessive buffer in simulation

The simulation model used introduced an artifact that have adversely affected the results. In simplifying the simulation implementation, retransmission delays were implemented as delayed events in the simulation. This effectively used the simulator's event queue as an oversized transmit queue causing large delays as the queue is emptied. A simple reduction of the MAC transmit queue would not be effective as packets (including the original beacon) may be dropped before they are first transmitted. A more accurate simulation model should have a very short MAC queue and implement a separate priority queue for prioritising retransmissions. The priority queue should be short enough such that all queued packets can be transmitted before expiry, and based on the retransmission metric, packets will be dropped when the queue overflows.

VII. Conclusion

In this paper we present a cooperative geocast algorithm that determines whether to retransmit based on estimated coverage and interference. The algorithm is effective in improving the dissemination of short packets over a prescribed area in the presence of both fast fading and shadowing. The algorithm uses a delay-based approach for prioritising packets, with the delay calculated based on a metric that accounts for additional node coverage and redundant or irrelevant packet reception. When compared to the alternative algorithms, the proposed algorithm is effective in reducing the interference caused by retransmissions, and degrades slower as node density increases. Since the operation of the algorithm only requires local information and information already in packet header, minimal overhead is required.

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