Inter Street Interference Cancelation in Urban Vehicular Networks Using Network Coding

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***Abstract*- An urban scenario is the center stage for vehicles to roam around the concrete jungle. Any sorts of wireless communication would be affected by hidden terminal problems, fading and interferences. Unintended nodes are unnecessarily bothered by such huge volume of microwave communications. The most common forms of communication are beaconing messages, which let the vehicles know about its neighboring vehicles and possibly choose an appropriate forwarder for safety and non-safety messages. However, such influx of broadcast messages may lead to beacon overhead and congestion resulting in low message reception as well as excessive delay. Interferences due to inter-street beacon messages may affect emergency messages, channel arbitration messages and other control messages which share a common channel as specified by DRSC/WAVE. This paper proposes a scheme to cancel interferences due to inter-street beacon communications by adaptive transmission control, while maintaining application layer transmission range, through multi-hop beacon forwarding and network coding. The simulations show that our scheme has higher packet delivery ratio and higher successful channel utilization compared to CSMA/CA protocols.**

***Index Terms*- Beacon, Congestion Control, Interference, Network Coding.**

I. INTRODUCTION

In recent years, communications in vehicular networks has witnessed a lot of attention from industry as well as academia due to many applications, such as collision notifications and avoidance, driver assistance, traffic monitoring and infotainment. The current trends in research show that Internet and cloud have encouraged the cyber penetration in vehicular networks in a big way. Various intelligent transportation systems (ITS) applications require a lot of data to be communicated over Vehicle-to-Vehicle (V2V) and Vehicle-Infrastructure (V2I) networks. In vehicular networks, beaconing is an important necessity to cater DSRC/WAVE safety applications [3] and the beacon frequency can go up to 10 beacons per second to deal with changes of directions, head-on collisions and rear end collisions of vehicles. Since GPS errors are inherent in vehicular networks, frequent beaconing is necessary to improve the accuracy of the neighborhood information in real-time.

We spend a significant amount of time commuting using either public transport or private transport. A vehicle may connect to a base station directly or through a mobile gateway [27]. Even cellular service providers may make use of vehicular networks to provide service through mobile offloading [28] to its passengers who are travelling through public private transport. Also, a plethora of incidents makes sensing in vehicular networks quite sensible and sensed data is forwarded through multi-hop. All these communications may have high bandwidth requirements. Assuming the future Wi-Fi and mobile communications would exploit vehicular networks, it can safety be concluded that vehicular networks would require a whole bunch of MAC and network layer protocols. The technical challenges in vehicular networks mostly include high mobility of vehicles, large differences in vehicle speeds; inter street interferences [29] and stringent delay and reliability requirements [3] of real-time applications. Accommodating several kinds of messages (i.e. beacon, control messages, emergency messages, and channel arbitration messages) generates considerable overload impacting the performance of the control channel [1].

In our approach, interferences from other vehicles which are not part of the same road segment are reduced by lowering the transmission power of each node. Unlike existing approaches [8][15-17][19], we have adaptively reduced the transmission power to obtain a transmission range much lower than the required transmission range for safety applications. However, to achieve the application layer transmission range[1] required by safety applications, we propose a forwarding mechanism that uses packet level network coding [22] to forward network coded beacons in multi-hop. Basically, a number of forwarding nodes, separated by certain distances, are preselected separated. When a forwarder receives beacon messages (i.e. either forwarded beacons or beacons by the source), from two opposite directions, it applies packet level network coding [22] to rebroadcast the resulting message and the process continues until the beacon message is not forwarded when the border of the application layer transmission range is reached. Our objective is by reducing the transmission power of beacon messages, we are able to manage congestion control and negate interferences.

The paper is organized as follows. Section II presents a detailed discussion of state-of-art and challenges. Section-III describes the proposed protocol. Section IV evaluates, via simulations, the performance of the proposed approach. Finally, Section-V outlines the conclusion and future work.

[1] We define the application layer transmission range is the distance within which all vehicles should receive beacons which is usually 300m for active-safety applications.

978-1-4799-3512-3/14/$31.00 ©2014 IEEE

II. RELATED WORKS

As per DSRC/WAVE standards [14], a single and separate channel is allocated to control messages, emergency messages and beacon messages. Various active safety applications [12], such as intersection collision warning, lane change assistance and pre-crash sensing warning, are heavily depended on utmost accuracy of beacon messages. By increasing beacon frequency, accuracy of beacons increases. However, the communication channel gets congested due to higher rate of beacons.

The analytical and simulation study of beacons, presented in [1], shows that an increase in node density increases channel busy time and decreases the reception probability of beacons. In [2], substantial reduction in beacon reception probability, in extremely saturated scenarios, is demonstrated. The combined impact of vehicle density, beacon frequency, and beacon packet size on reception probability is reported in [3]. To avoid beacon related problems, many beaconless emergency message dissemination mechanisms have been proposed in the literature [5-7][9][13].

Obstacles in forms of buildings, for example, play a major role in vehicular networks, as it can alter perspective altogether. In recent years, many realistic obstacle models have been developed for simulations [30]. These models add attenuation to the received signal. The attenuation is computed using map and building structures. However, the value of the attenuation varies drastically based upon maps and building structures. In city scenarios [30], the packet reception is usually lower than highway scenarios [30] due to the presence of interfering signals. Various loss recovery models using random linear network coding [25] for vehicular networks have been proposed in the literature. The authors in [24] proposed a sub-layer that optimizes the reliability of periodic broadcasting in VANETs applying random linear network coding which is used to provide reliability for small safety messages with low overhead; they also use message rebroadcasting to reduce congestion. In [25], a wireless broadcast retransmission scheme based on random linear network coding is proposed; the source code combines all lost packets to a single one by linear network coding for retransmission, and receivers are able to decode the original packets by Gaussian elimination when they receive enough coded-packets. The authors in [26], explored the benefit of Network Coding in improving the performance of repetition-based loss recovery for vehicular safety communications. The proposed a scheme which combines (XORs) packets from close-by neighbors and repeats the XORed packets instead of original packets, thereby creating the possibility of an increased number of packet recoveries per repetition.

VeMAC [20], supports one-hop and multi-hop broadcast services by using implicit acknowledgments and eliminating the hidden terminal problem. It reduces transmission collisions due to node mobility on the control channel by assigning disjoint sets of time slots to vehicles moving in opposite directions and to road side units.

Highly dynamic topologies and frequent changes in the network size make congestion control more challenging. Four main approaches have been adopted to reduce congestion incurred due to beacons: contention window adaptation [4][11], beacon rate adaptation [8][15][18], transmission duration adaptation [10] and transmit power adaptation [8][15-17][19]. The contention window based binary exponential back off algorithm (i.e. BEB) is considered as ineffective for broadcast messages [4]; however, a dynamic variation of contention window may enhance the network performances. In [11], an empirical formula is proposed to adapt CW depending on beacons received from neighbors during last few seconds.

Increasing beacon rate would provide more accurate information about neighbors at the cost of a higher collision probability. Schmidt et al. [15] discuss a trade-off between the accuracy of beacon information and the availability of bandwidth for emergency messages; they also propose an adaptive beaconing method in which the beacon frequency is adjusted based on a vehicle's own movement as well as on movement of the surrounding vehicles. CCC-MAC [10] is a time-slot-based medium access protocol that addresses channel congestion by reducing the transmission time of beacons through the use of multiple data rates; temporal and spatial partition addresses hidden terminal problem.

At a fixed beacon frequency, change in transmission power controls the number of nodes that share the common channel/bandwidth. Numerous transmission power control mechanisms, which adapt to change in node density, are proposed in the literature. A transmission power control scheme proposed by Artimy et al [17], estimates local traffic density for each node and determines the suitable transmission range; however, its main focus is to maintain connectivity rather than congestion control. Torrent-Moreno et al. [19] proposed a fair power adjustment algorithm for VANET where a vehicle adjusts its transmission power while keeping the beacon load within a predefined threshold. This always enables a part of the available bandwidth to be reserved for event driven messages; however, it requires transmission of beacons in multiple hops resulting in more overhead. Transmission control mechanisms work quite well in congestion scenarios; however, they suffer from scalability issues when congestion occurs even when the transmission power is at its lowest limit, as defined by DSRC standard [14].

Our proposed approach is unique since it adaptively reduces transmission power to get rid of interferences and congestion; to reduce channel usage due to forwarding of beacons, it uses packet level network coding (or linear network coding)[22].

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III. NETWORK CODING FOR INTERFERENE FREE PROTOCOL

The objective of the proposed protocol named Network Coding Based Interference Free (NC-IF) is to get rid of interferences due to inter street communication and hidden terminal problems. This can be achieved by reducing transmission range of each vehicle. This solves two purposes: (a) allows interferences free intra-street communications; and (b) reduces beacon load (reduces congestion). Assuming our system is aware of digital maps, the distance from a vehicle to nearby streets (i.e. other than Current Street) can be calculated. The transmission power control module deals with the adaptive transmission range. As the transmission range is reduced, multi-hop beacon transmission is needed to achieve the application layer transmission range; thus, a list of forwarding nodes, called network coding forwarders (NC-forwarders), must be preselected. The multi-hop network coding is explained next. With increase in hop-counts the delay may increase substantially; the timer and delay control module allows beacons to be forwarded in quickest time.

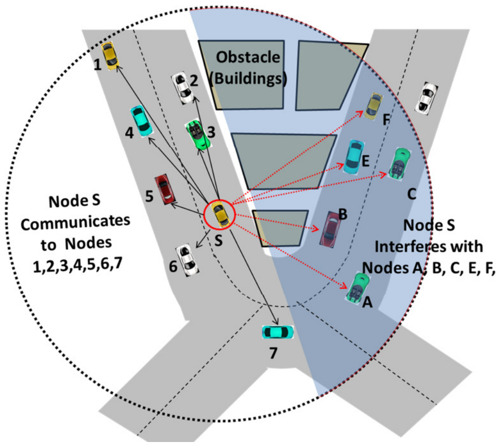

Fig 1. Inter-street interference

A. Motivations

In Fig. 1, when Node 'S' sends a beacon, it is received by other nodes in its neighborhood. It is important for nodes 1,2,3,4,5,6 and 7 to receive this beacon message as they share the same road segment with node 'S'. Nodes 'A', 'B', 'C', 'E' and 'F' may either receive successfully the beacon message, sent by 'S', or receive some interfering signals. Though, these nodes are within the transmission range of 'S', the beacon message comes through various building obstacles and the signal may be severely attenuated. Even if some of the nodes may receive the beacon message successfully, this is an undesired phenomena and the beacon of node 'S' would share bandwidth with nodes A', 'B', 'C', 'E' and 'F'. Therefore, node 'S' should reduce its transmission power and send beacons in multi-hop to reach neighboring nodes in the same road segment.

B. Dynamic Transmission Power Control

Most of DSRC based active-safety applications require an application layer transmission range (denoted by *R)* of about 300 meters [21]. To allow vehicles to receive beacons sent by vehicles *R* distance apart, forwarding nodes are needed to forward beacons in multi-hop. There will be a forwarding node to take care of the forwarding. But, at least one forwarder should be there within the transmission range even after reduction in power. The transmission range, denoted by *T, should* at least 50 meters (i.e., $M= 1/6^{th}$ of *R*) and at most *R.* The distance from a vehicle to nearby road segment (i.e. other than current road segment) is considered to be *D.* The initial value of T is:

$$T = \left\lceil \frac{D}{M} \right\rceil * D \qquad (1)$$

The transmission range *T* is a multiple of D. The initial value of *T* is the lowest transmission range a node possesses. However, in case of lower density scenarios, the Control Channel (CCH) [14] bandwidth is usually underutilized and the issue of congestion and hidden terminal problems may be of lesser importance while connectivity among neighboring nodes of more importance. Therefore, the transmission range should be increased even though few beacon packets get dropped due to inter street interferences and hidden terminal problems. The new transmission range becomes $T= T +D$ and it can go up to $T=R$. If the situation changes (i.e. higher density), the value of *T* would be computed using Equation (1).

C. Selection of NC-Forwarders

For multi-hop beacon forwarding, a group of vehicles must be preselected so that every vehicle can send its beacon within a transmission range of *R*. The method of selection should be distributed and should avoid inter-vehicle communications for the selection of forwarding nodes. We call these forwarding nodes as Network Coding Forwarders or NC-Forwarders. We assume that, the minimum distance between two adjacent NC-Forwarders must be 50m (i.e. same as *M*, the minimum transmission range). In a road segment, the selection starts from extreme south-west point. For example, let us consider that a road segment lies horizontal from left to right. node *P* in the extreme left declares itself as NC-Forwarder through its beacon. On receiving this beacon message, another node Q declares itself as NC-Forwarder, which is at least *M* apart from *P* and lies to the right side of *P*. On receiving the declaration of Q, a node in the neighborhood of *P* cannot declare itself NC-Forwarder. The process continues towards the right side of *Q*; indeed, all NC-Forwarders ensure that their moving direction is same as *P*. When a NC-Forwarder leaves a road segment, a new node takes over.

D. Multi-hop beacon forwarding and Network Coding

In our approach, the transmission power of each vehicle is reduced and using multi-hop beaconing messages are forwarded. As every vehicle broadcasts beacons, the resulting overhead will cause reducing transmission range; thus, the channel usage, by beacon messages, cannot be lowered and the multi-hop beacons will suffer from significant delay (i.e. hop delay, and queue delay). To reduce hop delay we adopt an efficient forwarding mechanism which is explained in section E. If the total number of packet transmissions can be reduced, it will lower queuing delay and contention delay. To overcome this issue and to obtain maximum benefits of a reduced transmission range, we exploit packet level network coding [22].

1) Forwarding Algorithm: The objective of this algorithm (i.e. Forwarding Node Selection (FNS)), is to improve overall throughput by applying packet level network coding. Each node maintains a coding table along with a neighbors table to take appropriate coding decisions. Neighbors table contains id, position, transmission power and speed of neighbors. Each entry in coding table includes NodeID and beacon received from a node.

On receiving a beacon, if the node is NC-Forwarder, it uses the position of the sender and transmission power of that sender to determine the forwarding region. If it finds itself inside the forwarding region, then it knows that it is one of the candidates to forward the beacon. If this NC-Forwarder is the farthest from the sender among all NC-Forwarders which are within the forwarding region, then this node is chosen as the forwarder for the sender.

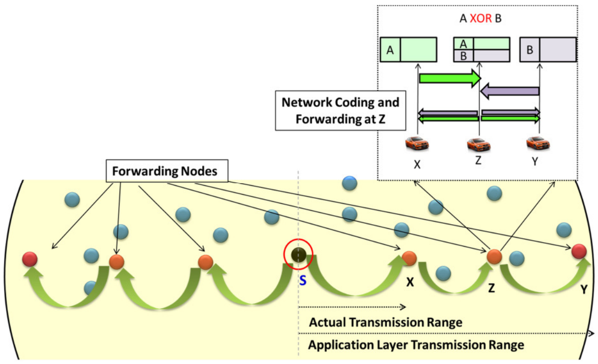

Fig 2. Multi-hop forwarding and network coding.

Given two received beacons, they can be coded only when their respective senders are not within range of each other. Let each of the beacons termed as the partner beacon. The node thus searches for a suitable partner in its coding table. For each entry in the code table, node ID is used to locate the neighbor entry in the neighbors table. Then, the neighbor dynamics, such as position, speed and acceleration of are processed to update position. The updated position is used to determine whether the beacon of the neighbor can serve as a partner beacon for the received beacon. If a partner beacon is found, the node XORs it with the received beacon and forms a coded beacon. Otherwise, the received beacon and the NodeID of the sender are added to the coding table and stored until a partner beacon is received.

As it is shown in Fig 2, node S has an application layer transmission range R. When the transmission range is reduced, the beacons are forwarded through, X, Y, and Z to one end. This process is replicated on the left side of node S. The beacon message from S is broadcasted and received by all neighbors of S including node X. Node X might have received beacon messages from its right. The job of node X is to apply network coding to these packets and rebroadcast. When node Z receives the network coded packet, it will extract the beacon which is sent by S and rebroadcast applying network coding. Node X and node Y broadcast beacons say A and B respectively. On receiving packets A and B, node Z performs XOR operation to create the coded packet A XOR B and broadcasts it. When node X and node Y receive the network coded packet, they can obtain each other's packet by XOR-ing again with their own packet.

To take maximum benefit from network coding, the forwarder should receive two beacon packets from opposing directions. If the forwarder has packets from a single direction, it goes to the stage of starvation if it does not receive any beacon packet from other directions. This will increase total delay in forwarding. Also, it is hardly possible that, immediately after receiving a packet from one direction another packet follows from another direction. Therefore, in our approach, the forwarder does not wait for another packet to form the network coding packet and forwards the packet immediately (i.e. within a short time period). If network coding packet (or forwarded beacon message) is ready and it has to contend with the forwarder's own beacon message, the network coding packet (or forwarded beacon message) is piggybacked with the beacon message.

E. Timer and delay Control

NC-forwarders broadcast network coding packets (or forwarded beacon messages), along with its own beacon messages. Such high number of message exchanges requires a scheduling mechanism. NC-Forwarders keep track of all idle period by sensing the medium. The durations in which the medium is sensed to be ideal, is divided into slots, nc-slots; a single slot is equivalent to a beacon transmission time. If the beacon message of a new vehicle is received or few beacon messages of an existing vehicle are not received, nc-slots are updated accordingly. When a NC-Forwarder receives two beacon messages from opposite sides with a maximum tolerance of Δ period, the network coding is applied and a new packet is scheduled to broadcast in next available nc-slot. If a new packet is received, but the next packet is not received from opposite direction after waiting for Δ period, the new packet is broadcasted directly without applying network coding.

F. Coding Gain Estimation

Let, n is the total number of vehicles in a road segment. Then, number of vehicles within a transmission range is given by n/h. In the proposed scheme, p fraction of the nodes is coded and (1-p) packets are forwarded without using network coding.

$$N_c = n + \frac{n}{h}(2-p)(h-1) \tag{2}$$

$$N_{wc} = n + \frac{2*n}{h}(h-1) \tag{3}$$

Nc and Nwc denotes the number of transmissions in case of the proposed scheme and number of transmissions when beacon is forwarded without using network coding. Since, p=3/4 in the proposed scheme, the gain which is given by N_{wc} / N_c is very high.

IV. PERFORMANCE EVALUATION

A. Performance Metrics

1) *Packet Delivery Ratio:* It is the ratio of the number of vehicles that receive the beacons to the total number of expected receivers. Since reliability is an important criterion for beacon dissemination, it is worthwhile to compare the proposed scheme with CSMA/CA in terms of packet delivery ratio.

2) *Successful channel busy time:* It is the average time period during which the channel is busy in successfully receiving beacons. It is measured at each node at the end of an observation period which is set to 1 sec. It is an indirect measure of channel utilization for successful message reception.

3) Average Beacon Forwarding Delay: It is the average delay to receive a beacon from a node to all other nodes within application layer transmission range (i.e. 300m).

4) Coding Gain: It is the ratio of packets transmitted without network coding to the number of packets transmitted with network coding.

Table- I
Simulation Parameters

Data Rate	3 Mbps
Transmission Range	50m,100m, 150m, 200m, 250m , 300m
Channel Model	Two Ray Ground
Number of Nodes	50-300
Number of Streets	4
Road Length	1 Km
Velocity	10m/s- 20m/s
Packet Size	200 Bytes
Random Noise	5dB-26dB
Number of Beacons	10 Beacons/Sec

B. Simulation Setup

Simulations are performed using an ns-2 simulator [23] to investigate the performance of the NC-IF protocol. Common simulation parameters are listed in Table I. For the simulation environments we choose four, 1k.m. lanes separated by 100m distance. Every time a beacon is forwarded, a random attenuation is added at the receiver end if the receiver does not belong to the same road segment. We choose Ns-2 for our simulations.

C. Results and Discussions

Fig 3 presents the comparison of packet delivery ratio for varying node density. With increase in node density, the packet delivery ratio (PDR) decreases for both the protocols. The impact of the interference is such that with node density CSMA/CA suffers from collisions and congestion in the channel. However, as NC-IF does not have interference the packets does not suffer from collision. Another important observation we would like to point out that, with very high densities, the degradation of PDR in CSMA/CA is very high. The cause of such severity is due to the fact that, apart from interference a lot of collision takes place which let many vehicles choose same beacon instance.

In Fig 4, we have compared the delay of our protocol /(NC-IF) with CSMA/CA. The CSMA/CA takes only one hop and we choose multiple hops to get rid of congestion and interference. However, the delay is so low that it, a vehicle does not change much (i.e. the new position is very close to old position which is in millimeters)

In Fig 5, it is noticed that both the protocols have identical channel busy time. We would like to point out that, even though we send extra packets, most of them are received successfully. Therefore the busy time in NC-IF does not change.

In Fig 6, the coding gain is shown. It is noticed that, the coding gain is as high as 1.3 which is around 30%.. Also, it can be noticed that the gain increases with increase in node density. The reason for that is with increase in node density, the transmission power is adaptively reduced and number of hops is increased. Therefore, the gain is higher with increase in node density.

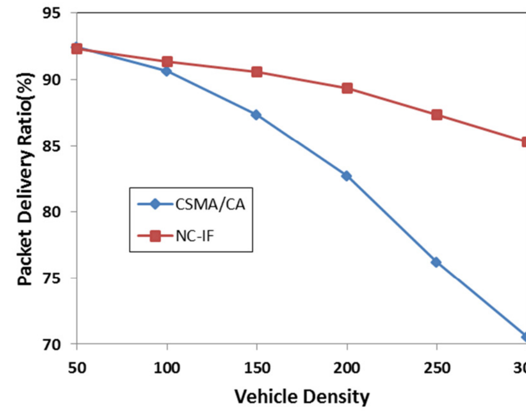

Fig 3. Packet Delivery Ratio

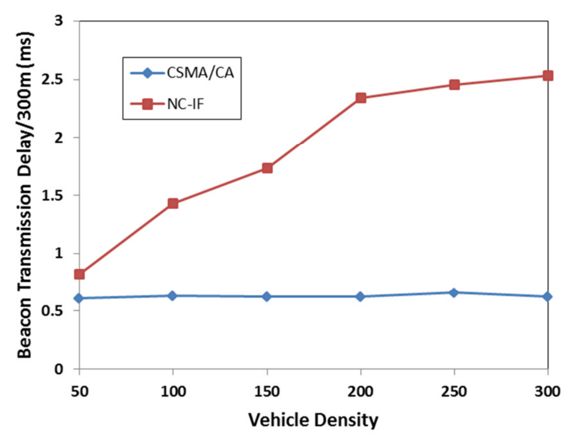

Fig 4. Beacon Transmission Delay within Application Layer Transmission Distance(i.e 300m)

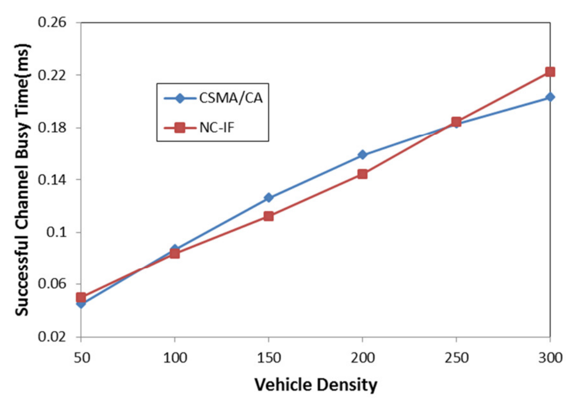

Fig 5. Successful Channel busy time (Amount of time a node spend in receiving packets successfully)

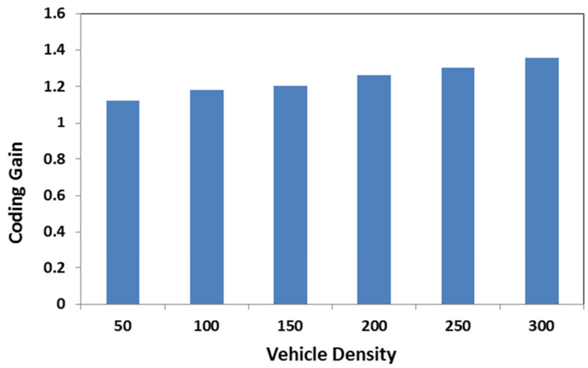

Fig 6 Coding Gain in NC-IF

V. CONCLUSION AND FUTURE WORKS

In this paper, we evaluated the benefit of network coding and adaptive transmission power control to reduce beacon overhead and inter-street interferences. By reducing the transmission range of beacons, the channel contention is reduced. Further, by exploiting packet level network coding, beacons can be delivered to receivers placed within the transmission range specified for safety applications. Simulations show that the proposed scheme outperforms the basic CSMA/CA scheme in terms of packet delivery ratio and successful channel busy time. Also, multi-hop beacon delay is under control which is evident from the simulations. The scalability of the proposed protocol is confirmed by the ability of nodes to send beacons to a significant number of its intended receivers in the high density scenario.

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