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Cooperation-Based Adaptive and Reliable MAC Design for Multichannel Directional Wireless IoT Networks

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ABSTRACT Internet of Things (IoT) is the ultimate enabler of modern civilization. Cooperative communication in multichannel directional wireless networks is one of the cutting-edge IoT research themes. Typically, cooperation in wireless networks is the opportunistic relaying of data packets for neighboring nodes by idle nodes. Current IoT-based researches related to multichannel with directional antenna introduce the control channel cooperation. But, the iterative phenomenon of negotiation in control channel results in higher communication delay. Hence, to reduce the data transmission delay, cooperation in data relaying need to be used along with control channel cooperation. In this paper, we propose a Cooperation-based Adaptive and Reliable MAC (CAR MAC) Design for Multichannel Directional Wireless IoT Networks that combines both of these cooperation and multichannel directional concepts of cooperation. Multichannel directional hidden terminal problems and deafness problems in medium access are solved using both concepts of cooperation jointly. Besides, multidirectional data packet relaying in the same data channel enables parallel transmission that increases the bandwidth utilization. Moreover, the proposed protocol uses a smart GPS (Global Positioning System) based neighbor discovery. Therefore, the directional position and distance among the IoT-enabled wireless nodes are smartly determined to make the control channel cooperation more informative. The results of extensive simulations reveal that CAR MAC achieves significant improvement in network performances.

INDEX TERMS Cooperative MAC, cooperation, hidden terminal, deafness, multichannel, omnidirectional, directional, antenna, control, relay node, distance.

I. INTRODUCTION

Nowadays, the use of *Internet of Things* (IoT) [1] devices dominates our daily life. Wireless IoT devices with latest IoT technologies [1] makes human lifestyle more easier and effective. Wireless networks consist with such IoT-enabled nodes and conduct communication among those are termed as wireless IoT network. Here, the key challenge is to conduct efficient communication among the wireless nodes.

Internet of Things (IoT) users can access remote information, applications as well as can communicate with each other. Likewise, traditional wireless communication IoT nodes exploits electromagnetic waves to convey the signal over part or the majority of the communication path. This ensures freedom of mobility and the proficiency to prolong applications to diverse parts of a building, city, or almost anywhere on the planet. In modern age, versatile IoT application-centric

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communication structures introduce different emerging and next generation networks [2]–[6].

In omnidirectional transmission system, due to electromagnetic energy transfusion to all directions an enormous amount of signals are dissipated; whereas, a tiny portion are received at the destination node. To address the solution of this limitation directional antennas [7] are invented to remove the inconvenience where an antenna is divided into multiple sectors and electromagnetic signals are transmitted at once by a specific sector. Most importantly channel capacity is enhanced through bandwidth utilization in terms of spatial reuse along with higher data rates provided by directional antennas.

In order to achieve aggregate utilization of the wireless medium multichannel wireless IoT network exploiting directional antennas results in better performance [8]. Here, parallel transmissions are achieved in the multichannel directional wireless IoT environment. Moreover, such revolutionary communication strategy improves the overall network capacity through gradual spatial sharing. However, hidden terminal, deafness or missing receiver problem and neighbor discovery problem are the key drawbacks of employing directional communication in a multichannel wireless IoT network [9], [10].

Recent wireless researches have imposed dimensions like cooperative communication in the context of *(i) information sharing*, *(ii) reliable data relaying* and *(iii) cooperation in multichannel resource allocation*. In traditional single-channel wireless networks, assignment of cooperative relays can turn up a raised degree of interference. High intensity of interference results in higher packet loss deteriorating the overall network throughput. On the contrary, multiple channels can be used to intensify the overall network performance to a great extent by reducing the impact of wireless interference.

Medium Access Control (MAC) protocols [11], [12] for such wireless IoT networks is a promising research domain; where, mostly omnidirectional antenna concept has been used for longer period of time. It is noteworthy that efficient MAC protocols are important for wireless IoT networks incorporating the mentioned features like directional use of multichannel resources along with cooperative communication. Though CMD MAC [13] has incorporated the directional multichannel and cooperative features; however, the cooperative concept is only used during the negotiation, not in data communication. As a result, for each of the data packet transmission CMD MAC experiences longer delay and more protocol overhead.

In this paper, we have designed and evaluated a novel directional MAC protocol in support of multichannel wireless IoT network environments and the protocol is named as CAR MAC. Multichannel directional hidden terminal and deafness problems of wireless IoT networks are solved through the procedure of CAR MAC for accomplishing successful communication using cooperation. Here, cooperation is ensured for two specific cases: firstly, for negotiation in control channel using control frames; as well as in data channel by relaying data frames. To the best of our knowledge, no research work has been conducted to solve the multichannel directional hidden terminal problems and deafness problems combining cooperative control frame and data frame concepts in wireless IoT networks.

Such protocol design considerations in data transmission ensures following benefits:

- Avoiding iterative control channel negotiation and that eliminates the resultant redundant and indefinite delay.
- Eliminating packet drop rate, that reduces the aggregate data transmission delay resulting in enhanced throughput.
- Ensuring parallel transmission in the same data channel, that assures higher bandwidth utilization

Besides, to resolve neighbor discovery problem use of smart GPS based neighbor discovery in proposed CAR MAC is another significant contribution. Due to frequent availability of GPS system in most recent wireless IoT nodes, such design concept used in neighbor discovery process to ascertain the directional position and distance among the wireless nodes. As a whole, proposed CAR MAC protocol combinations approaches like smart GPS based neighbor discovery, cooperative data communication, cooperative information sharing, directional transmission, multiple channels.

The remainder of this paper is organized as follows. We first review the state-of-the-art related works in Section II. In Section III, we discuss the difficulties in designing multichannel directional MAC protocols. We introduce our network model and assumptions in Section IV. In Section V, our proposed novel adaptive cooperation-based medium access protocol CAR MAC is narrated. The mathematical analysis and performance comparisons through simulation results are presented in Section VI and VII, respectively. Finally, we draw a comprehensive conclusion in Section VIII.

II. LITERATURE REVIEW

Initially, MAC protocols were designed for omnidirectional communication because wireless nodes were oriented with omnidirectional antennas. Authors provided different MAC schemes to solve the challenging issues or problems such as hidden and exposed terminal problems faced in medium access by such heterogeneous wireless nodes. At the initial stage in such research, authors proposed single-channel MAC protocols [11], [14] to solve these problems.

However, all of the single-channel schemes for MAC design use a shared channel for both of the control frame and data packet transmission that leads to collision. As a result, the overall network performance degrades. Since, single-channel MAC protocols cannot solve hidden and exposed terminal problems, authors consider that the use of additional channels can solve these problems. Thus, to ensure more fairness among the nodes in medium access and to avoid collision, multichannel omnidirectional MAC protocols [15], [16] evolved. These types of protocols permit various wireless nodes in a similar neighborhood to transmit simultaneously on various channels, while no interference will be introduced and results in enhanced network throughput. However, omnidirectional transmission concept using multichannel cannot fully eliminate hidden terminal problem.

A noticeable drawback of omnidirectional antenna system is the wastage of electromagnetic energy. To mitigate this drawback directional antenna [7] system has been introduced. S-MAC [17] is a single-channel directional MAC protocol that uses omnidirectional transmission mode for control packets broadcasting and directional mode for data packet transmission. S-MAC alike protocols [18], [19] prevent deafness problem by transmitting control frame omnidirectionally. On the other hand, hidden terminal problem still exists due to omnidirectional control packet collision. Nodes other than the source and destination overhear the control packet may block their related antenna directions.

To utilize the advantages of spatial reuse in single-channel directional MAC protocols, the idea of directional control frames (i.e., DTRS/DCTS) was introduced in [20]. So, there is no unnecessary blocking of neighbor node's antenna sectors. However, due to directional RTS/CTS exchange, directional hidden terminal and deafness problems are introduced. To solve these problems, extra control frames are used and huge network delay accrued. Besides, circular RTS/CTS based single-channel directional MAC protocol [21] was introduced to solve the directional hidden terminal and deafness problems occurring for directional RTS/CTS exchange. Still, excessive network delay and energy consumption have come about as a result of circularly transmitting directional RTS/CTS frames.

PCD-MAC [22] is a power controlled version of single-channel directional MAC protocol; where, the control packets are transmitted omnidirectionally to all the sectors of directional antenna by adapting the transmitting power level for each sector to transmit furthest directional limit except hampering transmissions that are in progress. Finally, directional DATA/ACK frames are exchanged by minimal requisite transmission power. However, single-channel wireless IoT network environment with directional communication is still vulnerable due to directional hidden terminal and deafness problem.

A recent research trend of wireless communication combines the use of directional antennas and multichannel [8]. Here, parallel transmissions can be performed not only in different channels but also within the same channel in different directions through the utilization of directional features of antennas. Therefore, the cutting-edge feature of communication enhances direction-wise spatial sharing and boosts up the network capacity to a large extent.

Numerous directional MAC protocols [23], [24] adopted the multichannel concept by logically splitting a single-channel into two noninterfering separate channels. However, two logical channels cannot fulfill the outcomes of original multichannel directional MAC protocol. DSDMAC [24] is a tone-based directional MAC protocol that uses two separate channels one for omnidirectional tone signal and another for directional control/DATA transmission. Here, single-channel directional hidden terminal problem still exists for directional RTS/CTS/DATA/ACK transmission in a sole data channel.

In MCDA [9] and MMAC-DA [10], multichannel concept increases the utilization of network bandwidth through utilizing spatial reuse and achieves higher throughput by minimizing the overall network delay. However, information insufficiency is the climacteric drawback of multichannel wireless networks with such single radio oriented wireless nodes. Because, nodes do not have the concurrent access capability on multiple frequency channels and results in data collision for multichannel hidden terminal problem and redundant retransmissions for deafness or missing receiver problem. On the other hand, MCMDA [25] is a multi-radio oriented multichannel directional MAC protocol where nodes are equipped with multiple radios and each radio can be tuned to multiple data channels as because there is no control channel. However, channel rendezvous for nodes is a difficult task without a common control channel and higher energy will be consumed by the nodes due to multiple-radio concept.

CAM-MAC [26] is the first cooperative MAC protocol that proposed the idea of cooperation in the multichannel environment. The protocol has solved the major drawbacks of such network environment, i.e., the multichannel hidden terminal problems and deafness problems employing a recent concept of cooperation named control channel cooperation which is a distributed information sharing (DISH) process.

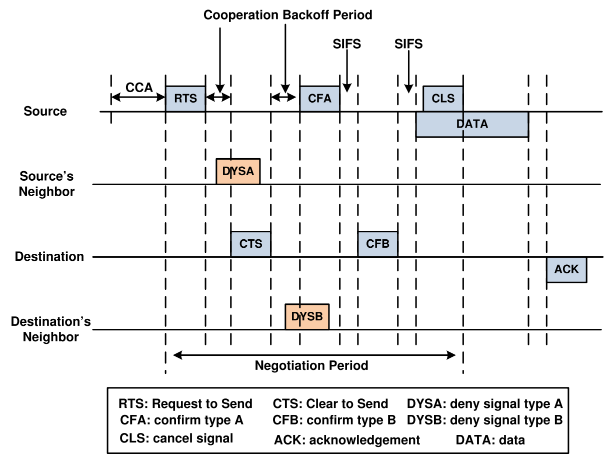

FIGURE 1. Protocol operation of CMD MAC protocol.

CMD MAC [13] is a recent cooperative directional MAC protocol that emphasizes the improvement of network throughput in a multichannel directional network environment by associating directional transmission systems. To solve the multichannel directional hidden terminal problems and deafness problems CMD MAC also utilizes distributed information sharing (DISH) [26] based control channel cooperation. To progress the network performance CMD MAC jointly uses multiple channels, single radio, omnidirectional cooperative negotiation, directional data transmission. Fig. 1 demonstrates the protocol operation of CMD MAC protocol. Until now, cooperation in wireless IoT networks represents the relaying of data packets by the nodes intermediary between source and destination. However, this concept of cooperation conflicts with the conventional idea of cooperation and prolong the communication time for recurrent control channel negotiation resulting in higher communication delay and minimizing overall network throughput.

III. CHALLENGES AND MOTIVATION

In this section, the challenges in designing a multichannel directional MAC protocol are discussed. An ideal multichannel directional MAC protocol supposed to address these mentioned challenges for better network performances.

A. NEIGHBOR DISCOVERY AND LOCALIZATION

The IoT-enabled wireless nodes equipped with directional antennas need to recognize their neighbors as well as their directions with each of the neighbors using the positional coordinates. Directional neighbor discovery determines the exact position of all neighbors and their direction. Numerous researches [27], [28] has been carried out on directional antenna based neighbor discovery processes. Majority of these papers uses control frame (i.e., RTS/CTS) overhearing based neighbor discovery; where, a node measures the distance from another node using the Received Signal Strength Indicator (RSSI) value [29]. The node can also get location information or position of other neighbor nodes and estimate the direction toward them by applying approaches like Angle-of-Arrival (AoA) [29], [30], Time-of-Arrival (ToA) [29] and Time-Difference-of-Arrival (TDoA) [29]. Additionally, the Global Positioning System (GPS) based neighbor discovery procedure is also an effective approach [27], [30].

However, neighbor discovery system with distance-based localization process using one of the techniques RSSI, AoA, ToA or TDoA is not reliable for a dense network where nodes have mobility issues. Due to mobilization in different channel as well as in different location all of the neighboring nodes might not be able to overhear the broadcasted control frames.

B. DIRECTIONAL HIDDEN TERMINAL PROBLEMS

If a wireless node is not aware of another ongoing transmission and due to the unawareness, its control packets (i.e.,RTS/CTS/ACK) and data packets (DATA) can bring about collisions with the ongoing transmission, then this node is called a hidden terminal. Multichannel and multiple antenna directionality are two network parameters those are responsible for occurring hidden terminal problems. Multichannel directional hidden terminal Problem is a combination of two diverse hidden terminal problems - namely, directional hidden terminal problem with Single Data Channel and Omnidirectional Hidden Terminal Problem with Multiple Data Channels. In case of the combined multichannel directional hidden terminal problem, channel and direction are two matrices to identify, whether a node is found as hidden by other node. Besides, directional mode in control packet transmission in control channel also creates two different types of hidden terminal problems - namely, directional hidden terminal problem for asynchronous antenna gain and directional hidden terminal problem due to unheard control frames.

1) DIRECTIONAL HIDDEN TERMINAL PROBLEM WITH SINGLE DATA CHANNEL

As demonstrated in Fig. 2, due to unknown status of a shared channel by a source, directional hidden terminal problem occurs. During channel negotiation between nodes (E, F) for potential directional data transmission, nodes (A, B) are involved in another directional data transmission and after completing that node B again intended to directionally transmit data to C. Since, node B is uninformed about the directional communication from nodes (E, F), it transmits directional RTS packet for C. This RTS packet may cause collision at node F. Such collision mainly occurs for using single-channel both for channel negotiation and data transmission.

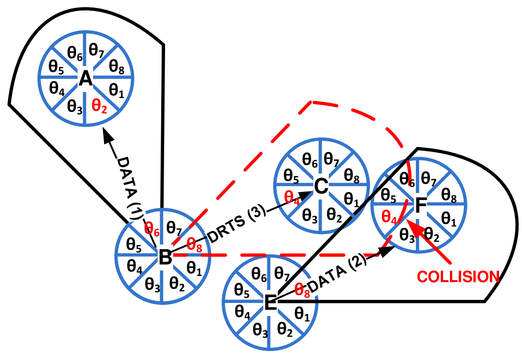

FIGURE 2. Directional hidden terminal problem with single data channel (DC).

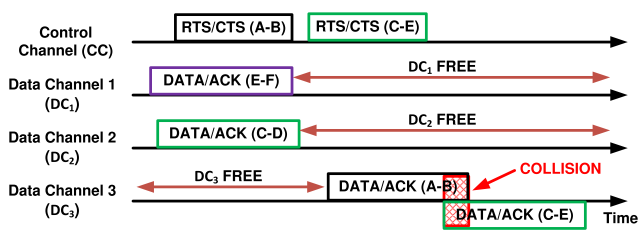

FIGURE 3. Omnidirectional hidden terminal problem with multiple data channels.

2) OMNIDIRECTIONAL HIDDEN TERMINAL PROBLEM WITH MULTIPLE DATA CHANNELS

Omnidirectional Hidden Terminal Problem with Multiple Data Channels takes place if a pair of nodes unintentionally tries to communicate in an already occupied channel for omnidirectional data transmission. According to Fig. 3, nodes (C, D) and (E, F) are exchanging data omnidirectionally on DC_2 and DC_1, respectively. Concurrently, nodes (A, B) are carrying out RTS/CTS handshake in control channel to pick a data channel for prospective omnidirectional data transmission. Nodes (A, B) select DC_3 and switch to DC_3 for data transmission. Meanwhile, after completing respective communications both pair of nodes (C, D) and (E, F) switch back to control channel. Instantly, node C has data packets to exchange with E. If nodes (C, E) negotiate for selecting a data channel and unaware about the ongoing omnidirectional data communication of nodes (A, B) in DC_3, it might select the same channel. Though at that time DC_1 and DC_2 both are in idle state. Such instance may arise if nodes (C, E) have missed the RTS/CTS control packets of negotiation between nodes (A, B) in control channel. As a result, the communications between nodes (A, B) and (C, E) conflict with each other.

3) DIRECTIONAL HIDDEN TERMINAL PROBLEM FOR ASYNCHRONOUS ANTENNA GAIN

This form of the hidden terminal problem evolves because of the coexistence of omnidirectional and directional transmission mode [31]. Fig. 4 exemplifies a wireless network consisting of three nodes A, B and C. Initially, the radios of all nodes are in omnidirectional mode with gain G^o and all the nodes know the directional position of each other. Steering its beam direction toward node C, node B sends a *directional RTS* (DRTS and at that time node C is in omnidirectional mode. Thereupon, node C switches into directional mode with gain G^d and sends back a *directional CTS* (DCTS). It is assumed that node A does not overhear the DCTS of C because of its far distance from C with gain G^o. After completing the negotiation nodes (B, C) steer their corresponding beams to each other for potential data transmission. Still now, node A is incapable of perceiving the communication in progress due to its omnidirectional mode. Meanwhile, if node A seeks to transmit data to B, it immediately continues DVCS until it finds the channel vacant and transmit data directionally. Here, node A and B are in the same direction from node C. In mentioned scenario there is a high probability that node A's DRTS may interfere with the DATA reception at node C.

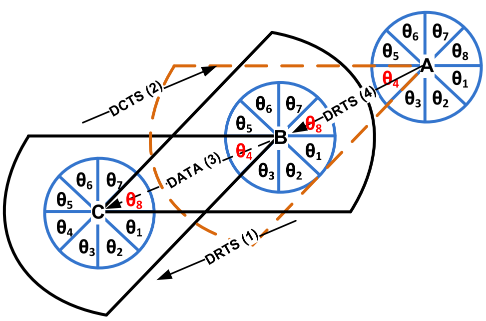

FIGURE 4. Hidden terminal problem due to asynchronous antenna gains.

4) DIRECTIONAL HIDDEN TERMINAL PROBLEM DUE TO UNHEARD CONTROL FRAMES

As the scenario depicted in Fig. 5, when node C transmits directional DATA to D and nodes (B, A) are in omnidirectional mode. Node B switches in directional mode and sends DRTS to A. Subsequently, node A replies with a DCTS. In the meantime, node A's DCTS can get through to node C. Nevertheless, node C cannot overhear the DCTS packet because C is directionally beamformed toward D. Hence, node C does not concentrate on all other directions except the direction toward D, as a result it cannot overhear either DRTS or DCTS. Upon completing the communication with D if C initiates another communication to A by sending DRTS, it may interfere with A's ongoing DATA reception.

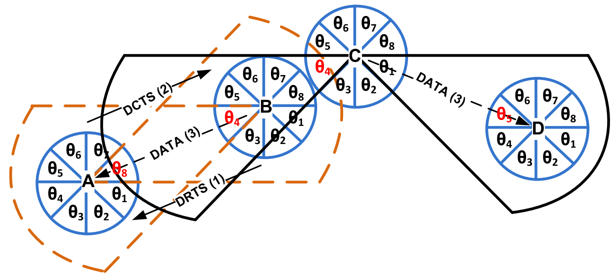

FIGURE 5. Hidden terminal problem due to unheard control frames.

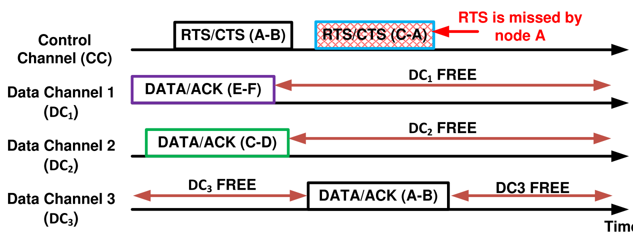

FIGURE 6. Deafness or missing receiver problem due to multichannel environment.

C. DEAFNESS OR MISSING RECEIVER PROBLEM

1) DEAFNESS DUE TO MULTICHANNEL ENVIRONMENT

Deafness arises in multichannel environment when a source is found unsuccessful to communicate with its desired destination due to unknown status (i.e., channel state) of destination. As demonstrated in Fig. 6, if nodes (A, B) negotiates in control channel and at same time instance nodes (E, F), (C, D) exchange DATA/ACK omnidirectionally at DC_1 and DC_2, respectively. Here, nodes C, D, E and F fail to overhear the RTS and CTS from A and B, respectively. After completing the negotiation nodes (A, B) switch to DC_3 for omnidirectional data transmission. Meanwhile, nodes (C, D) and (E, F) finish communication and switch back to control channel. Now, if node C intends to communicate with A and starts channel negotiation with RTS broadcasting, node A fails to receive that and eventually will not reply with CTS.

2) DEAFNESS DUE TO DIRECTIONAL ANTENNAS

Specially, such deafness arises when a source becomes unsuccessful to exchange control frame/packet with destination due to its different direction alignments. As in Fig. 7, illustrates

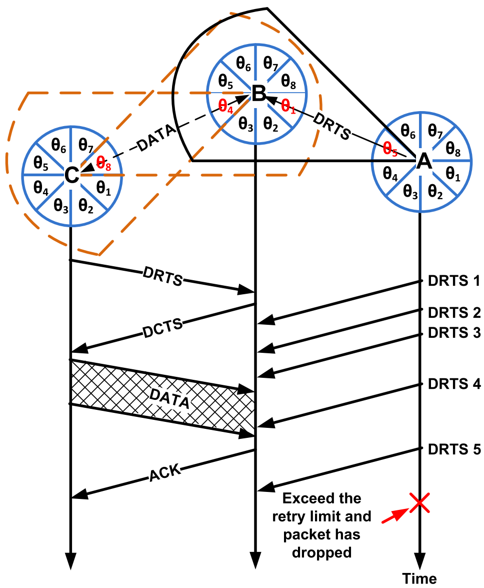

FIGURE 7. **Deafness due to directional antennas.**

node B is directed toward C and B's DNAV blocks the beam directed to A. Consequently, node B cannot receive node A's DRTS. Meanwhile, if node A sends DRTS to B, then B will be unable to reply with a DCTS.

D. MOTIVATION

A lot of research works have been done to address the above-mentioned challenges and problems in designing multichannel directional MAC protocols for wireless networks [10], [13], [25], [26]. However, most of those protocols only resolve multichannel directional hidden terminal and deafness problems but the guaranteed data delivery issue is rarely addressed at those works. Therefore, we are motivated to think of a protocol named CAR MAC which targets to accomplish the following objectives:

1) To design an efficient multichannel directional MAC protocol for wireless IoT networks not only to solve the traditional hidden terminal and deafness problem but also to ensure guaranteed data delivery.
2) To minimize the redundant and indefinite delay for iterative control channel negotiation.
3) To increase network throughput by diminishing the aggregate data communication delay utilizing eschewed packet drop using cooperative data relaying.
4) To enhance bandwidth utilization through performing simultaneous data communication in an identical data channel using directional data transmission.

IV. NETWORK MODEL AND ASSUMPTIONS

A. ASYNCHRONOUS NETWORK STRUCTURE

An asynchronous ad hoc wireless IoT network is assumed where the IoT-enabled nodes are distributed in a uniform random manner. Each node having a unique MAC address can be identified individually. For a unit area (A), the network density (ρ) is defined as the prospective amount of IoT-enabled nodes (n) that exist in the same area A; therefore, $\rho = n/A$ and it is assumed that at any moment $\rho > 0$. If the spatial difference between the source (S) and destination (D) is Ψ, then a prospective amount of candidate relay nodes (n) between S and D is calculated as [32]:

$$n = \rho\pi\left(\frac{\Psi}{2}\right)^2 \tag{1}$$

From the spread spectrum, the non-overlapped and static channels Industrial, Scientific and Medical (ISM) band is considered for the sake of proposed protocol operation. The features of distance based data rates of IEEE 802.11b [33] MAC standard are adopted for best cooperative relay (r) selection. However, the IEEE 802.11g/n/ac [33] MAC standards are also applicable in our proposed CAR MAC protocol since these standards also provide different distance based data rates. Among the available channels one channel is dedicated for exchanging the omnidirectional control packets named as control channel, whereas the rest of the channels are used for potential directional data communication defined as data channels. It is also assumed that proposed CAR MAC not only performs simultaneous data communications in multiple data channels but also performs parallel data communications in a single-channel.

B. ANTENNA MODEL

In CAR MAC, it is assumed that a single radio transceiver is associated with each IoT-enabled wireless node and operations are made in half-duplex mode. Hence, during communication, it can either transmit or receive electromagnetic radio signals. It is also assumed that the radio transceiver able to switch among a group of independent frequency channels. However, it can access a single channel at once. In addition, both omnidirectional and directional transmission modes are assumed here. As demonstrated in Fig. 8, the transmission range and gain of directional transmission mode (G^{d}) is greater than the omnidirectional transmission mode (G^{o}).

TABLE 1. **Notations used in system model and assumptions.**

Symbol	Definition
ρ	Node density
n	Expected number of nodes
A	Area to estimate node density (ρ)
Ψ	Distance between source and destination
G^O	Antenna gain in omnidirectional mode
G^d	Antenna gain in directional mode
θ	Antenna beamwidth
M	Number of sectors/beams in an antenna
G_{main}	Gain of main-lobe
G_{minor}	Gain of minor-lobe

It is assumed that the antenna is steerable [34]; i.e., each node can point its antenna in any desired direction. Total

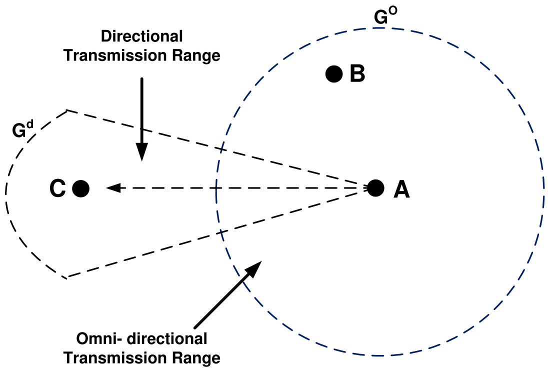

FIGURE 8. The omnidirectional and directional transmission range of a directional antenna.

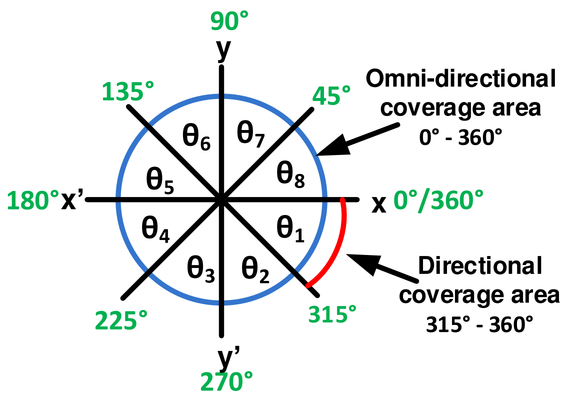

FIGURE 9. Antenna model.

of "M" non-overlapping sectors or beams provide coverage around the antenna, where each sector or beam having angle or beamwidth θ ($0 < \theta \leq 2\pi$) and radius equal to the maximum transmission/reception range. So, the antenna sectors are individually treated as directional antennas and can either transmit or receive signals. If "M" numbers of sectors or directional antennas are obtained by partitioning a transceiver then "$2\pi/M$" radians is the angle/beamwidth of each directional antenna or sector. Further, antenna beams have fixed indexing as $\theta_1, \theta_2, \ldots, \theta_M$ initiating at the 3 o'clock position and directing counter clockwise [34]. Furthermore, the stable directional position of the beams of a transceiver of IoT-enabled wireless node despite the node's mobility as depicted in Fig. 9. Besides, the switching delay for different communicational modes as well as antenna sectors are negligible as per the concept of [34].

During operation among total M directional antennas or sectors only one sector remains active and having the capability of maximum radiation/reception of electromagnetic signal to a fixed direction. This high gain sector is called main-lobe and remaining ($M - 1$) low gained sectors directed to different directions are termed as minor-lobes or back lobes. The proposed work assumed the idealized directional antenna pattern termed as "flat-top" antenna model where the gain of minor-lobes are assumed to be very low [27], [35] and the minor-lobe effect is negligible, i.e., the antenna gain is fixed within the beamwidth θ of a particular main-lobe beam and the gain outside the beamwidth considered as zero. Therefore, the identical antenna gains of the main-lobe and minor-lobe are given by $G_{\text{main}} = 2\pi/\theta$ and $G_{\text{minor}} = 0$ respectively, where θ is the beamwidth of a beam. Moreover, based on the spatial distance from Source-to-relay ($S-2-r$) and relay-to-Destination ($r-2-D$) variable data rates are achieved during communication from ($S-2-r$) and ($r-2-D$) ascertain in D^2RAC MAC [36]. In the same way, a recent research SCT [35] ensures that distance-based multiple data rates are supported by the directional antenna system as shown in Fig. 10.

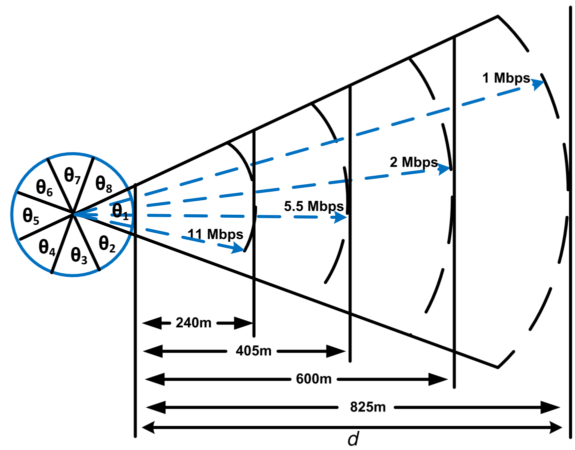

FIGURE 10. Distance-based multiple data rates using IEEE 802.11b in directional antenna model.

C. GPS ENABLED NODE

Since, each IoT node is equipped with Global Positioning System (GPS), IoT nodes are capable of determining the accurate location of its own and overhear the location of all neighboring nodes through control frames [37]. Using GPS coordinate information a node calculates the distance and directional position of each of its neighbor nodes from its own.

V. CAR MAC PROTOCOL OPERATION

The proposed CAR MAC protocol operation is narrated in four subsections namely, neighbor discovery, reliability-based relay selection, control frame structure and link establishment negotiation with transmission mode selection.

A. NEIGHBOR DISCOVERY

Neighbor discovery is one of the prime difficulties in directional IoT networks. In our proposed CAR MAC protocol, the neighbor discovery procedure is divided into two distinct parts defined as GPS-based neighbor discovery and overhearing-based neighbor discovery. GPS-based neighbor discovery is used to determine the distance and direction among the nodes. Whereas, nodes channel uses information is

TABLE 2. Notations used in CAR MAC operation.

Symbol	Definition
(x_i, y_i)	Longitude and latitude value of i^{th} node
$d_{[i,j]}$	Distance from i^{th} to j^{th} node
θ_L	Angular lower threshold
θ_U	Angular upper threshold
$\theta_{[i,j]}$	i^{th} to j^{th} node antenna sector ID
f_{r_i}	Cooperation Backoff Period of i^{th} relay
ξ_{r_i}	Combined metric value of i^{th} relay
ϕ	A constant time unit
κ	Maximum backoff time threshold
T_{r_i}	Data transmission time of i^{th} relay
Υ_{r_i}	Energy-efficiency parameter of i^{th} relay
ψ_{r_i}	Cooperative reliability factor of i^{th} relay
L_{DATA}	Data packet size
L_{ACK}	Acknowledgment frame size
R_{S-r_i}	Data-rate from Source to relay
R_{r_i-D}	Data-rate from relay to Destination
T_{SIFS}	Short Interframe Space time
E_{r_i}	Initial energy of i^{th} relay
$E_{r_i}^{res}$	Residual energy of i^{th} relay
$P_{r_i}^{C}$	Cooperative relaying power of i^{th} relay
P_S^D	Direct transmission power of source
$\mu_{r_i D}$	i^{th} relay to destination Packet error rate
T_w	Waiting time
T_{CBP}	Cooperative backoff time period
T_{TMOUT}^{MCTS}	MCTS timeout period

ascertained through the overhearing-based neighbor discovery process.

1) GPS-BASED NEIGHBOR DISCOVERY

To discover the exact location of a IoT node, the coordinate value obtained by GPS is used to determine the distance and angular direction between the nodes. Nodes store this information in the two following matrices:

a: NODE DISTANCE MATRIX

Each node contains a node distance matrix in its memory. The calculated distance from a node to all of its neighbor nodes and the distance among all of the neighbor nodes are stored in this matrix. Euclidean distance between two points in the geographic plane with coordinates (x_1, y_1) and (x_2, y_2) is given by [30].

$$dist((x_1, y_1), (x_2, y_2)) = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \quad (2)$$

where, x and y are the longitude and latitude of those points.

As shown in Fig. 11, the Euclidean distance between $n_1(x_1, y_1)$ and $n_2(x_2, y_2)$ is measured and stored at each node distance matrix. Each node distance matrix is formed as follows:

$$d_{dist} = \begin{bmatrix} d_{[1,2]} & d_{[1,3]} & \cdots & d_{[1,N]} \\ \vdots & \vdots & \ddots & \vdots \\ d_{[N,1]} & d_{[N,2]} & \cdots & d_{[N,N-1]} \end{bmatrix}$$

Here, $d_{[i,j]}$ represents the distance between i^{th} to jth node.

b: NODE ANTENNA DIRECTION MATRIX

Each node maintains an antenna direction matrix to avoid potential interference from the same direction and same channel. Here the directions are identified by the sector (θ).

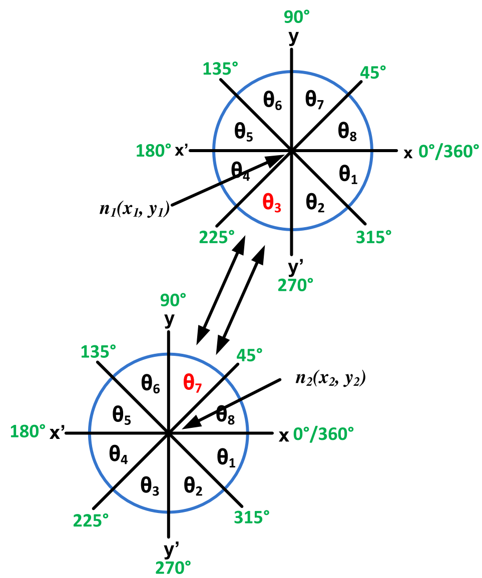

FIGURE 11. Neighbor node's antenna direction and distance discovery through GPS.

Equation 3 is used to determine the angle between two nodes and the sector identifiers (IDs) for this angle as well. The angle at which each of the sectors steers for directional communication has two angular threshold value denoted as Lower threshold (θ_L) and Upper threshold (θ_U). By calculating θ_L and θ_U values, a node n_1 can determine its own sector ID using which it will directionally communicate to another node n_2 and vice versa (as demonstrated in Table 3). So, the angle between $n_1(x_1, y_1)$ and $n_2(x_2, y_2)$ can be calculated as:

$$\theta = tan^{-1}\left(\frac{y_2 - y_1}{x_2 - x_1}\right) \pm \frac{2\pi}{M} \quad (3)$$

where, M is the total number of sectors and $M = 0, 2, 4, \ldots, 2m$.

$$\theta_L = tan^{-1}\left(\frac{y_2 - y_1}{x_2 - x_1}\right) - \frac{2\pi}{M} \quad (4)$$

$$\theta_U = tan^{-1}\left(\frac{y_2 - y_1}{x_2 - x_1}\right) + \frac{2\pi}{M} \quad (5)$$

To generate the node antenna direction matrix, a node perform the operation of equation 4 and equation 5 for every direction based on the value of M to calculate the sector ID for directional communication among other nodes. Therefore, a node can determine the sector in which it can communicate directionally with another node at any geographical position (as shown in Fig. 12). Table 3 demonstrates the sector-wise relationship of a node with respect to its neighbors. Finally, obtained values are stored in the following node-directional matrix:

$$\theta_{dir} = \begin{bmatrix} \theta_{[1,2]} & \theta_{[1,3]} & \cdots & \theta_{[1,N]} \\ \vdots & \vdots & \ddots & \vdots \\ \theta_{[N,1]} & \theta_{[N,2]} & \cdots & \theta_{[N,N-1]} \end{bmatrix}$$

Here, $\theta_{[i,j]}$ represents the i^{th} to j^{th} node antenna sector ID.

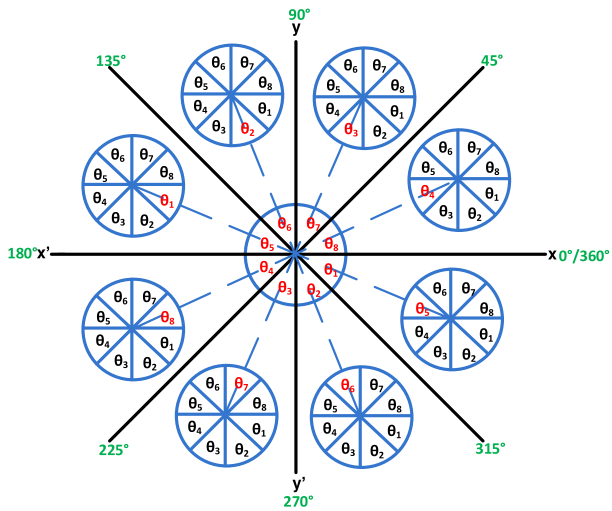

FIGURE 12. Sector wise relation in between two nodes at any geographical location.

TABLE 3. Sector-wise directional relationship.

Sender Node		Receiver Node	
Sector ID	$\theta_L - \theta_U$	*Sector ID*	$\theta_L - \theta_U$
θ_1	*315°- 360°*	θ_5	*135°- 180°*
θ_2	*270°- 315°*	θ_6	*90°- 135°*
θ_3	*225°- 270°*	θ_7	*45°- 90°*
θ_4	*180°- 225°*	θ_8	*0°- 45°*
θ_5	*135°- 180°*	θ_1	*315°- 360°*
θ_6	*90°- 135°*	θ_2	*270°- 315°*
θ_7	*45°- 90°*	θ_3	*225°- 270°*
θ_8	*0°- 45°*	θ_4	*180°- 225°*

2) OVERHEARING-BASED NEIGHBOR DISCOVERY

In most of the contemporary researches, the neighbor discovery process is based on control message overhearing only. But, we have introduced GPS based distance and directional information gathering along with distributed channel uses information sharing by control message overhearing. This combined approach among the nodes is applied in CAR MAC protocol to eliminate the hidden terminal problems in multichannel environment along with achieving parallel transmissions for higher bandwidth utilization.

TABLE 4. Channel-direction information table (CDIT).

Node ID	Accessible Channels with Sectors: $DC_N(\theta_1, \theta_2, ..., \theta_M)$
A	$DC_1(\theta_1,\theta_4,\theta_6)$, $DC_2(\theta_1,\theta_3,\theta_5,\theta_7,\theta_8)$, $DC_5(\theta_4,\theta_7)$, $DC_6(\theta_1,\theta_4,\theta_7)$, $DC_7(\theta_2,\theta_3,\theta_8)$, ..., $DC_N(\theta_1,\theta_2,\theta_6)$
B	$DC_1(\theta_1,\theta_5,\theta_6)$, $DC_3(\theta_1,\theta_2,\theta_5)$, $DC_4(\theta_1,\theta_3,\theta_6,\theta_7)$, $DC_6(\theta_4,\theta_7,\theta_8)$, ..., $DC_7(\theta_2,\theta_5,\theta_8)$
C	$DC_3(\theta_1,\theta_4,\theta_8)$, $DC_4(\theta_1,\theta_4,\theta_6,\theta_7)$, $DC_5(\theta_3,\theta_5,\theta_6)$, $DC_6(\theta_1,\theta_4,\theta_7)$, $DC_8(\theta_2,\theta_5,\theta_8)$, ..., $DC_N(\theta_1,\theta_5,\theta_8)$
D	$DC_1(\theta_1,\theta_4,\theta_6,\theta_8)$, $DC_2(\theta_2,\theta_3,\theta_5,\theta_7)$, $DC_4(\theta_5,\theta_7)$, $DC_5(\theta_2,\theta_3)$, $DC_8(\theta_1,\theta_4,\theta_8)$, ..., $DC_N(\theta_1,\theta_3,\theta_5,\theta_6)$
E	DC_2 $(\theta_1,\theta_4,\theta_8)$, $DC_3(\theta_3,\theta_7)$, DC_6 $(\theta_1,(\theta_4,\theta_7,\theta_8)$, $DC_8(\theta_1,\theta_3,\theta_4,\theta_5,\theta_8)$, ..., $DC_N(\theta_1,\theta_2,\theta_3,\theta_3,\theta_6)$

Using directional network allocation vector (DNAV) and the information obtained through overheard control packets, each node yields a Channel-Direction Information Table (CDIT). During negotiation for an intended communication, wireless nodes are able to take proficient decisions using the up to date CDIT because this table always keeps up to date on the basis of DNAV. As shown in Table 4, the CDIT of a node holds the details of its neighbor nodes and their accessible channel list along with the usable directional sectors. During negotiation at the control channel, nodes have to overhear or receive regular control packets from its neighbor to produce CDIT. After receiving a control packet, nodes also update the DNAV to block a specific sector of a particular channel for an intended communication period. While a node gets particulars of a new neighbor it instantly registers that node's identity (MAC Address) in its CDIT along with accessible channels and the available sectors.

The use of CDIT accomplish following key objectives:

- Decreasing power consumption by avoiding collisions as a consequence of multichannel hidden terminals.
- Enhancing the capability of channels through executing parallel directional data communication in an identical data channel.

B. RELIABILITY-BASED RELAY SELECTION PROCESS

The efficiency of a cooperative MAC protocol undoubtedly relies on the selection of an optimal or best relay in between source (S) and destination (D). In presence of multiple candidate relay nodes it is necessary to select an optimal or best relay based on certain relay selection parameters that affect the throughput and overall network performance. In CAR MAC, we propose a reliability-based optimal or best relay selection process that considers nodes data transmission time along with few reliability parameters, namely data rate, cooperative reliability factor, instantaneous residual energy and distance.

According to the proposed relay selection strategy, candidate relay nodes estimate their Cooperation Backoff Period (CBP) and perform countdown of CBP utilizing CSMA-based mechanism. The relay node with the minimum estimated CBP value will become zero and selected as the best or optimal relay (r). The Cooperation Backoff Period (CBP) for i-th relay is defined as:

$$f_{r_i} = \phi \times min\left(\xi_{r_i}, \kappa\right) \tag{6}$$

where, ξ_{r_i} is the combined metric value of all relay selection parameters for i-th relay and κ is the maximum backoff time threshold, used to bound the backoff time within a limited range. Here, ϕ is a constant time unit(i.e., in millisecond)that limits the maximum backoff time by $\phi.\kappa$. The combined metric value ξ_{r_i} is calculated as:

$$\xi_{r_i} = \left(T_{r_i} + \Upsilon_{r_i} + \psi_{r_i}\right) \tag{7}$$

where, T_{r_i}, Υ_{r_i} and ψ_{r_i} are the total data transmission time in the data channel, energy-efficiency parameter and cooperative reliability factor, respectively of i-th relay node. T_{r_i} is estimated as:

$$T_{r_i} = (L_{DATA} + L_{ACK})\left(\frac{1}{R_{S-r_i}} + \frac{1}{R_{r_i-D}}\right) + 3T_{SIFS} \tag{8}$$

where, L_{DATA} is the data packet size and L_{ACK} is the acknowledgment frame size. R_{S-r_i} and R_{r_i-D} are achievable data-rate from $S-2-r_i$ and r_i-2-D, respectively. One of the former research named D^{2}RAC MAC [36] demonstrates data-rates can be estimated based on distance. Eventually, estimated distances among the nodes are stored in node distance matrix during neighbor discovery period. T_{SIFS} is the Short Interframe Space (SIFS) period. The energy-efficiency parameter (Υ_{r_i}) for i-th relay node is calculated as [38]:

$$\Upsilon_{r_i} = \frac{E_{r_i}}{E^{res}_{r_i}} \times \frac{2P^C_{r_i}}{P^D_S} \tag{9}$$

where, E_{r_i} is the initial energy and $E^{res}_{r_i}$ is the instantaneous residual energy of i-th relay node. Besides, $P^C_{r_i}$ denotes the transmission power of i-th relay node during cooperative relaying and P^D_S is the transmission power of source node (S) in direct transmission mode. If μ_{r_iD} is the packet error rate from i-th relay to destination (D) then cooperative reliability factor (ψ_{r_i}) of i-th relay node is estimated as [39]:

$$\psi_{r_i} = \frac{1}{\mu_{r_iD}} \tag{10}$$

If more than one relay node estimate the same CBP value(i.e., using equation 6); then to ensure reliability in data transmission the node having higher data rate from $S-2-r_i$ than that of data rate from r_i-2-D (i.e., $R_{S-r_i} > R_{r_i-D}$) will be nominated as the relay node.

C. CONTROL FRAME STRUCTURE

In proposed CAR MAC, all the control frames consists of location information (LOC_INF), node identifier of its transmitter (TX_ADR) and node identifier (RX_ADR) of its receiver. Fig. 13 demonstrates the formats of all control frames. Source (S) begins channel negotiation with Request-to-Send (RTS) frame transmission to destination (D) and D replies with Clear-to-Send (CTS). In RTS/CTS frame, the negotiating pair attaches the prospective data channel (CH_ID), sector ID (SEC_ID) and duration or Time Span (TS) of communication. By overhearing the RTS/CTS, the neighboring nodes update the CDIT and DNAV. If D receives a Cancel Transmission (CTR) from one of its neighbor after the CTS transmission, D will transmit a modified CTS (MCTS) to S.

After receiving RTS, if the D perceives the existence of a hidden node, it transmits Veto-from-Destination (VTD) control packet to S to refuse S's intended communication. The Live Node Address (LN_ADR) in VTD represents the hidden node for which the ''veto'' frame has introduced and Left Time Span (LTS) exhibits the remaining active time of the corresponding link.

After overhearing the RTS/CTS, neighbors in between S and D inspects their DNAVs and CDIT. If a neighbor traces a possible collision, it will transmit Veto-from-Neighbor (VTN) frame to S to obstruct the direct transmission. VTN also represents the willingness of that neighbor to relay the data packet from S to D. VTN conveys the CH_ID acquired from CDIT and the corresponding SEC_ID from S to cooperator or relay ($S-2-r$) node and relay to D ($r-2-D$) for relaying data packet directionally. LN_ADR and LTS represent the same as mentioned earlier in VTN/CTR. Time Span (TS) is the duration of the proposed link.

In response to the CTS frame, CTR is provided by one of the D's neighbors that located in the opposite direction of S from the D to exhibit veto for the direct communication. Note that, both of the VTD and CTR frame have the same structure. The neighbors in between S and D tends to cooperate by relaying data packet take part in Cooperation Backoff Period (CBP) and the node with minimum backoff value expires first and transmits Reservation (RES) frame to S. The CH_ID, SEC_ID from $S-2-r$ & $r-2-D$, LTS and TS the same as mentioned earlier in VTN. Here, Acknowledgment (ACK) frame is used for the confirmation of successful data reception by the destination in data channel.

D. LINK ESTABLISHMENT NEGOTIATION PROCESS

The Direct Transmission Mode (DTM) and Cooperative Transmission Mode (CTM) are two distinct operational modes that adaptively appear during the operation of the proposed CAR MAC protocol.

1) DIRECT TRANSMISSION MODE (DTM)

When source (S) intends to perform a directional data communication with destination (D); S makes out the non-existence of other traffic before transmitting on the basis of Clear Channel Assessment Carrier Sense (CCA-CA) (as demonstrated in Fig. 14). After identifying the idleness of control channel, S commences negotiation for data channel (DC) assignment by sending a RTS. A DC will be selected

RTS / CTS / MCTS (25 Bytes)

FC	TS	TX_ADR	LOC_INF	RX_ADR	CH_ID	SEC_ID	SEQ_NO	FCS
(2 bytes)	(2 bytes)	(6 bytes)	(4 bytes)	(6 bytes)	(1 bytes)	(1 bytes)	(1 bytes)	(2 bytes)

VTD / CTR (31 Bytes)

FC	TX_ADR	LOC_INF	RX_ADR	LN_ADR	LN_CH SEC	LTS	SEQ_NO	FCS
(2 bytes)	(6 bytes)	(4 bytes)	(6 bytes)	(6 bytes)	(2 bytes)	(2 bytes)	(1 bytes)	(2 bytes)

VTN (36 Bytes)

FC	TX_ADR	LOC_INF	RX_ADR	LN_ADR	LN_CH SEC	LTS	CH_ID	S-2-r & r-2-D SEC_ID	TS	SEQ_NO	FCS
(2 bytes)	(6 bytes)	(4 bytes)	(6 bytes)	(6 bytes)	(2 bytes)	(2 bytes)	(1 bytes)	(2 bytes)	(2 bytes)	(1 bytes)	(2 bytes)

RES (26 Bytes)

FC	TX_ADR	LOC_INF	RX_ADR	CH_ID	S-2-r & r-2-D SEC_ID	TS	SEQ_NO	FCS
(2 bytes)	(6 bytes)	(4 bytes)	(6 bytes)	(1 bytes)	(2 bytes)	(2 bytes)	(1 bytes)	(2 bytes)

ACK (5 Bytes)

FC	SEQ_NO	FCS
(2 bytes)	(1 bytes)	(2 bytes)

Shortened Form:

CH_ID: Channel Identifier LOC_INF: Location Information VTD: Veto-from-Destination RES: Reservation
LTS: Left Time Span SEQ_NO: Sequence Number FCS: Frame Check Sequence CTR: Cancel Transmission
FC: Frame Control RX_ADR: Receiver Address LN_ADR: Live Node Address VTN: Veto-from-Neighbour
SEC_ID: Sector Identifier TX_ADR: Transmitter Address LN_CH_SEC: Live Node Channel and Sector Identifier
S-2-r & r-2-D SEC_ID: Source-to-relay & relay-to-Destination Sector Identifier TS: Time Span MCTS: Modified CTS

FIGURE 13. Frame format of CAR MAC.

where the intended directional communication between S and D will not be affected by any hidden node. RTS frame contains proposed data channel ID (DC_{N}) and sector ID (θ_{M}) to communicate directionally with D. All the neighbors along with the D will receive this RTS. The RTS eavesdropped neighboring nodes in between S and D including D inspects respective DNAVs and the CDIT to identify probable collisions. If neither neighbors nor D identifies any probable collision then nodes keep tacit. Upon receiving RTS, D will respond with CTS for channel reservation performing IEEE 802.11 Distributed Coordination Function (DCF). CTS frame also contains data Channel ID (C_{N}) and Sector ID (θ_{M}) proposed by D for S's intended communication.

Upon receiving the CTS, S waits for a period (T_w^1) to identify veto from neighbors or MCTS form D. If such veto or MCTS packet does not appear then the negotiation DC assignment becomes successful. The neighbors updated respective DNAVs based on the newly established link information. Meanwhile, S and D shift to the nominated DC after waiting T_w^1 period and S begins to transmit data packet directional using the assigned sector after a Short Interframe Space (SIFS). Finally, the D responds with an ACK frame to conclude the communication afterward finishing the data reception. The waiting period (T_w^1) is estimated as:

$$T_w^1 = 2T_{CBP} + T_{TMOUT}^{MCTS} \tag{11}$$

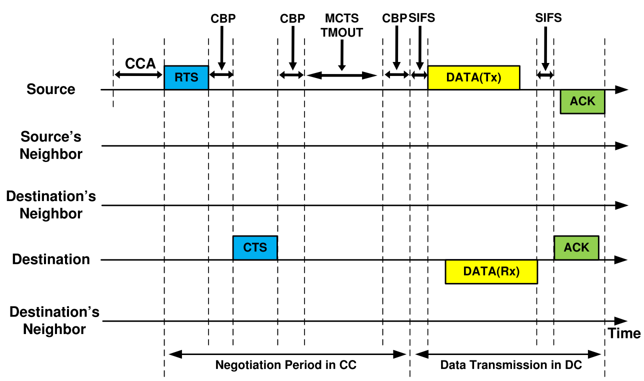

FIGURE 14. The CAR MAC operation for direct transmission mode (DTM).

2) COOPERATIVE TRANSMISSION MODE (CTM)

The DTM of the proposed CAR MAC protocol switches in CTM to adapt with the following four distinct network scenarios [40].

Scenario-1: After eavesdropping RTS frame neighbor nodes inspect respective DNAV and CDIT. If a neighbor in between S and D discovers a probable data collision then it broadcasts Veto-from-Neighbor (VTN) control frame (as illustrated in Fig. 15). By broadcasting VTN, the neighbor node alerts S about the imminent collision and expresses its willingness to relay data packet directionally from S to D. If multiple neighbors identify such a problem and

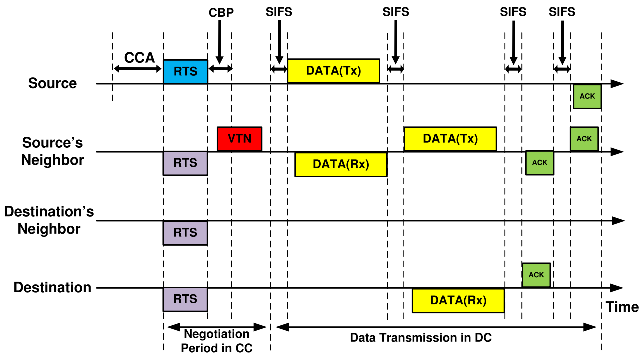

FIGURE 15. **CTM operation of scenario-1 in CAR MAC.**

desire to cooperate by relaying the data packet; then the optimal or best relay will be selected from those neighbors using the proposed reliability-based relay selection process as described earlier. VTN contains the accessible CH_ID and the SEC_IDs for directional data transmission from $S-2-r$ and $r-2-D$. Relay node collects this information from the node-directional matrix and CDIT. After overhearing the recent channel assignment neighbor nodes upgrade respective DNAVs.

Meanwhile, relay (r), S and D shift in the nominated DC. Waiting a SIFS period data packet is transmitted directionally from $S-2-r$ using the designated sectors. Thereupon, waiting for a SIFS period relay (r) transmits data packet directionally to the intended D. To notify successful data packet reception, directional ACK control frame is transmitted from $D-2-r$ and $r-2-S$. Finally, relay, S and D return to the CC. Here, directional hidden terminal and deafness problems are solved through cooperative information sharing. Besides, cooperative data relaying in multichannel environment assures successful data communication within a single negotiation process.

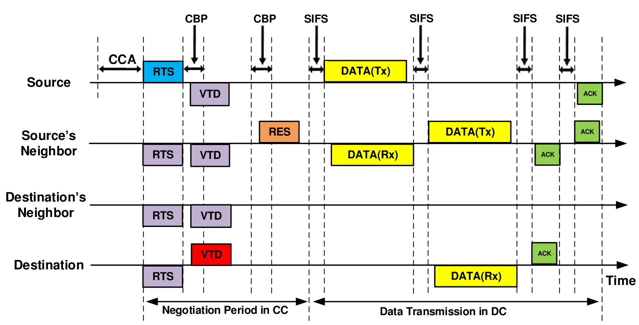

FIGURE 16. **CTM operation of scenario-2 in CAR MAC.**

Scenario-2: Accordingly, D scrutinizes its DNAV, CDIT after receiving RTS. If D identifies a probable data collision then it transmits Veto-from-Destination (VTD) control frame to S to obstruct the desired direct transmission (as shown in Fig. 16). Neighbor nodes in between S and D overhear the VTD frame. Interested neighbors to relay data take part in CBP and reservation (RES) frame is transmitted to the

Algorithm 1 CAR MAC Algorithm

Nodes broadcast (RTS, CTS, VTN, VTR, CTR, MCTS, RES) control frames during negotiation in CC
Nodes generate *CDIT* by overhearing control frames
Nodes generate d_{dist} and θ_{dir} matrixes using GPS coordinate values
if *S sends RTS to D* **then**
    if *D replies with CTS* **then**
        S and D switches to DC after waiting T_w^1 period and direct data communication occurs
    else if *relay* (r) *sends VTN to S and D* **then**
        S, D and r switch to DC and cooperative data communication occurs
    else if *D replies with VTD; overhearing VTD relay* (r) *sends VTN to S and D* **then**
        S, D and r switch to DC and cooperative data communication occurs
    else if *D replies with CTS; overhearing CTS relay* (r) *sends VTN to S and D* **then**
        S, D and r switch to DC and cooperative data communication occurs
    else if *D replies with CTS; a neighbor sends CTR to D and D sends MCTS to S* **then**
        S and D switches to DC after waiting T_w^2 period and direct data communication occurs
    else if *D replies with CTS; a neighbor sends CTR to D; D sends MCTS to S; overhearing MCTS relay*(r) *sends VTN to S and D* **then**
        S, D and r switch to DC and cooperative data communication occurs
    else
        Executing CCA, S resends RTS to D
    end if
end if

S by best relay (r). The RES control frame is also received by the D. Similarly, RES contains the accessible CH_ID and the SEC_IDs for directional data transmission from $S-2-r$ and $r-2-D$. This information also collected from the node-directional matrix and CDIT. The CBP estimation process, reliability-based best relay selection process and the directional data communication process are the same as mentioned earlier in Scenario-1.

Scenario-3: After overhearing the CTS, neighbors inspect respective DNAV and the CDIT (as depicted in fig. 17). If a neighbor in between S and D discovers a potential data collision, then it broadcasts VTN control frame to provide veto. By broadcasting the VTN neighbor node alerts S about the imminent collision and expresses its willingness for directionally relaying data packet from S to D. In the case of multiple neighbors, the best relay (r) sends the VTN to S. VTN control frame is also received by the D. Besides, if this same problem is identified by one of the neighbors of D which is not located in between S and D; then it

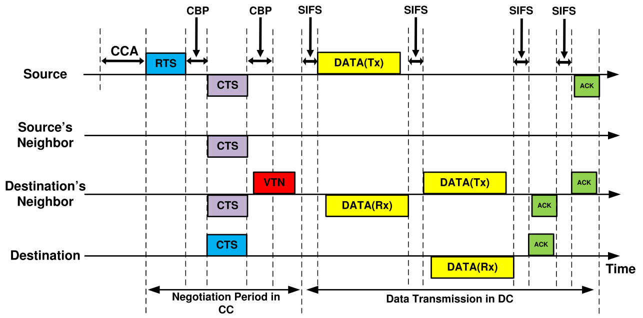

FIGURE 17. CTM operation of scenario-3 in CAR MAC.

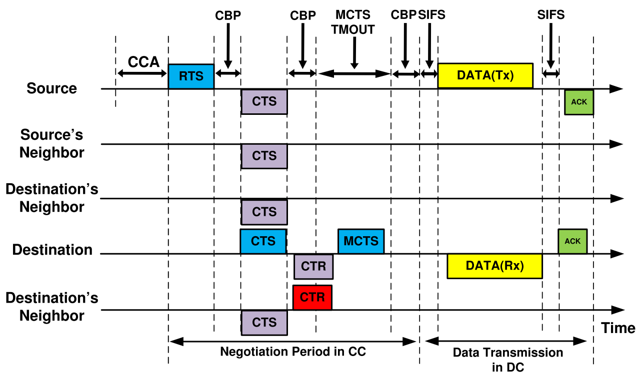

FIGURE 18. Opportunistic DTM operation during scenario-3 in CAR MAC.

transmits Cancel Transmission (CTR) control frame to D. Upon receiving CTR, D modifies the values of the initial CTS frame and sends the Modified CTS (MCTS) frame to S again. During MCTS TMOUT period S will receive the MCTS control frame and anticipate for veto frame for T_w^2 waiting period to terminate the prospective direct communication. Throughout the T_w^2 period, if any veto frame is not received by S then opportunistically it will start directional direct data communication with D (as depicted in fig. 18). Besides that, the protocol switches to the CTM of network scenarios-4. The waiting period (T_w^2) is estimated as:

$$T_w^2 = T_{CBP} \tag{12}$$

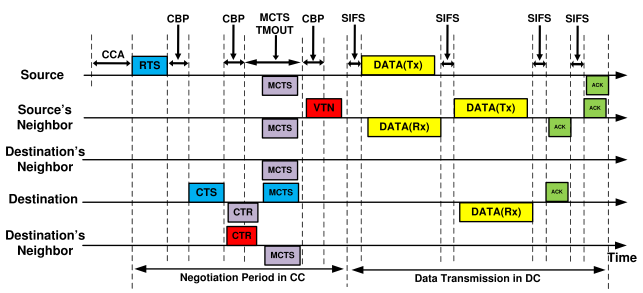

FIGURE 19. CTM operation of scenario-4 in CAR MAC.

Scenario-4: Thereafter S anticipate for veto frame for T_w^2 waiting period after receiving the MCTS frame from D to terminate the prospective direct communication (as demonstrated in fig. 19). The neighbors in between S and D also overhear MCTS frame. If a neighbor in between S and D discovers a potential data collision, then it broadcasts VTN control frame to provide veto. VTN frame alerts the S about the imminent collision and expresses its willingness for directionally relaying data packet from S to D. If multiple neighbors identify such a problem and desire to cooperate by relaying the data packet; then the optimal or best relay selection process and directional data communication process are similar as described earlier in network scenarios-1.

VI. PROTOCOL ANALYSIS

A. COOPERATIVE TRANSMISSION DELAY

We have imitated the model of RD^{2}C MAC [39] to analyze the cooperative delay of the multichannel directional wireless IoT network model of the proposed CAR MAC. To make a directional data communication successful, cooperative transmission considered for four distinct network scenarios. Due to the diverse cooperative transmission process, each of these network scenarios experiences different cooperative transmission delays. Now, the delay of network scenario-1 is estimated as:

$$\delta_{ns_1} = T_{VTN} + T_{CBP} \tag{13}$$

Considering network scenario-2, the cooperative transmission delay is calculated as:

$$\delta_{ns_2} = T_{VTD} + T_{RES} + 2T_{CBP} \tag{14}$$

and, the cooperative transmission delay of network scenario-3 is computed as:

$$\delta_{ns_3} = T_{VTN} + 2T_{CBP} \tag{15}$$

Similarly, the cooperative transmission delay of network scenario-4 is measured as:

$$\delta_{ns_3} = T_{CTR} + T_{MCTS} + T_{VTN} + 3T_{CBP} \tag{16}$$

B. COOPERATIVE TRANSMISSION TIME

The overall cooperative transmission time of our proposed protocol also differs based on the four diverse network scenarios and for each of the network scenarios total cooperative transmission time denoted as $T_{coop}^{ns_1}$, $T_{coop}^{ns_2}$, $T_{coop}^{ns_3}$ and $T_{coop}^{ns_4}$. Here, the total cooperative transmission time for network scenario-1 ($T_{coop}^{ns_1}$) is calculated as [39]:

$$T_{coop}^{ns_1} = \delta_{ns_1} + 2\left(T_{DATA} + T_{ACK}\right) \tag{17}$$

where, T_{DATA} is the data transmission time from S-2-r or r-2-D and T_{ACK} is the time to transmit acknowledgment from D-2-r or r-2-S.

Again, for network scenario-2 the total cooperative transmission time ($T_{coop}^{ns_2}$) is estimated as:

$$T_{coop}^{ns_2} = \delta_{ns_2} + 2\left(T_{DATA} + T_{ACK}\right) \tag{18}$$

Similarly, the entire cooperative transmission time for network scenario-3 ($T_{coop}^{ns_3}$) is measured as:

$$T_{coop}^{ns_3} = \delta_{ns_3} + 2\left(T_{DATA} + T_{ACK}\right) \tag{19}$$

Finally, the total cooperative transmission time for network scenario-4 ($T_{coop}^{ns_4}$) is measured as:

$$T_{coop}^{ns_4} = \delta_{ns_4} + 2\,(T_{DATA} + T_{ACK}) \tag{20}$$

C. COOPERATIVE THROUGHPUT ANALYSIS

In accordance with the proposed multichannel directional MAC protocol, the packet error rate for $S-2-r$ communication and $r-2-D$ communication of the two-hop cooperative directional communication are denoted as μ_{S-r} and μ_{r-D}. Now, μ_{S-r} and μ_{r-D} are estimated as [32]:

$$\mu_{S-r} \approx \frac{d_{S-r}^{\beta}}{\lambda_{S-r}} \tag{21}$$

$$\mu_{r-D} \approx \frac{d_{r-D}^{\beta}}{\lambda_{r-D}} \tag{22}$$

where, λ, β and d denote the Signal-to-Interference-Plus-Noise Ratio (SINR) value, path-loss factor and the spatial distance between transmitting and receiving node, respectively.

Now, the cooperative success rate (χ_{coop}) for the two-hop cooperative directional communication can be formulated as [39]:

$$\chi_{coop} = (1-\mu_{S-r}) \times (1-\mu_{r-D}) \tag{23}$$

Hence, the cooperative throughput (φ_{coop}) for each of the cooperative network scenarios of our proposed CAR MAC protocol can be represented as:

$$\varphi_{coop}^{ns_1} = \chi_{coop} \times \delta_{ns_1} \tag{24}$$

$$\varphi_{coop}^{ns_2} = \chi_{coop} \times \delta_{ns_2} \tag{25}$$

$$\varphi_{coop}^{ns_3} = \chi_{coop} \times \delta_{ns_3} \tag{26}$$

$$\varphi_{coop}^{ns_4} = \chi_{coop} \times \delta_{ns_4} \tag{27}$$

D. COOPERATIVE ENERGY CONSUMPTION

According to our proposed CAR MAC protocol, the total power consumption for a successful cooperative directional communication is summation of the power consumption for successful cooperative directional data packet relaying and successful cooperative directional ACK frame relaying. Hence, the total power consumption (W_{coop}) for a successful cooperative directional communication can be represented as:

$$W_{coop} = W(L_{DATA}, d_{S-D}) + W(L_{ACK}, d_{S-D}) \tag{28}$$

where, $W(L_{DATA}, d_{S-D})$ and $W(L_{ACK}, d_{D-S})$ denotes the power consumption of successful cooperative directional data packet relaying and successful cooperative directional ACK frame relaying, respectively. Again, L_{DATA} and L_{ACK} represents the data packet size and acknowledgment frame size. Furthermore, d_{S-D} represents the spatial distance among source (S) and destination (D). Now, according to [39], [41] $W(L_{DATA}, d_{S-D})$ and $W(L_{ACK}, d_{D-S})$ are given by:

$$\begin{aligned} W(L_{DATA}, d_{S-D}) = {} & W_{tx,S}(L_{DATA}, d_{S-r}) \\ & + W_{rx,r}(L_{DATA}) + \big[W_{tx,r}(L_{DATA}, d_{r-D}) \\ & + W_{rx,D}(L_{DATA})\big] \times (1-\rho_{S-r}) \end{aligned} \tag{29}$$

$$\begin{aligned} W(L_{ACK}, d_{D-S}) = {} & W_{tx,D}(L_{ACK}, d_{D-r}) \\ & + W_{rx,r}(L_{ACK}) + \big[W_{tx,r}(L_{ACK}, d_{r-S}) \\ & + W_{rx,S}(L_{ACK})\big] \times (1-\rho_{D-r}) \end{aligned} \tag{30}$$

where, W_{tx} and W_{rx} is the power consumption for wireless signal transmission and reception, respectively. Again, both of d_{Sr} and d_{rD} represents the spatial distances. Moreover, ρ_{S-r} and ρ_{D-r} denote the probability of successful data packet transmission from $S-2-r$ and the probability of successful acknowledgment frame transmission from $D-2-r$, respectively.

Now, equation 29 and equation 30 can be simplified as given by [39]:

$$\begin{aligned} W(L_{DATA}, d_{S-D}) = {} & L_{DATA}[(\frac{W_{a,S}}{\eta_a} \times d_{S-r}^{\beta}) + W_{rx,r} \\ & + \{\{(\frac{W_{a,r}}{\eta_a} \times d_{r-D}^{\beta}) \\ & + W_{rx,D}\} \times (1-\rho_{S-r})\}] \end{aligned} \tag{31}$$

$$\begin{aligned} W(L_{ACK}, d_{D-S}) = {} & L_{ACK}[(\frac{W_{a,D}}{\eta_a} \times d_{D-r}^{\beta}) + W_{rx,r} \\ & + \{\{(\frac{W_{a,r}}{\eta_a} \times d_{r-S}^{\beta}) \\ & + W_{rx,S}\} \times (1-\rho_{D-r})\}] \end{aligned} \tag{32}$$

where, W_a represents transmission amplifier's energy dissipation. Again, η_a denotes the amplifier efficiency in case of wireless signal transmission with a value of $\eta_a = 0.06e^{0.095P_{tx}} dBm$.

Now, substituting the values of equation 31 and equation 32 into equation 28, we acquire the value of W_{coop} as:

$$\begin{aligned} W_{coop} = {} & L_{DATA}[(\frac{W_{a,S}}{\eta_a} \times d_{S-r}^{\beta}) + W_{rx,r} \\ & + \{\{(\frac{W_{a,r}}{\eta_a} \times d_{r-D}^{\beta}) + W_{rx,D}\} \times (1-\rho_{S-r})\}] \\ & + L_{ACK}[(\frac{W_{a,D}}{\eta_a} \times d_{D-r}^{\beta}) + W_{rx,r} \\ & + \{\{(\frac{W_{a,r}}{\eta_a} \times d_{r-S}^{\beta}) + W_{rx,S}\} \times (1-\rho_{D-r})\}] \end{aligned} \tag{33}$$

Using the data rates R_{S-r} and R_{r-D} for wireless transmissions from $S-2-r$ and $r-2-D$; the cooperative data rate (R_{coop}) for that cooperative communication can be derived as:

$$R_{coop} = \frac{R_{S-r} \times R_{r-D}}{R_{S-r} + R_{r-D}} \tag{34}$$

Finally, if the cooperative directional transmission time (T_{coop}) is one of the T_{ns_1}, T_{ns_2}, T_{ns_3} or T_{ns_4}; then we can express the cooperative energy consumption (E_{coop}) as:

$$E_{coop} = \frac{W_{coop}}{R_{coop}} \times T_{coop} \tag{35}$$

E. COOPERATIVE END-TO-END DELAY

The cooperative end-to-end delay for two-hop communication from $S-2-r$ and $r-2-D$ is the summation of delays for individual communication from $S-2-r$ and $r-2-D$. Hence,

TABLE 5. Notations used in protocol analysis.

Symbol	Definition
δ_{ns_i}	Cooperative transmission delay in network scenario-i
$T_{coop}^{ns_i}$	Total cooperative transmission time in network scenario-i
μ_{S-r} / μ_{r-D}	Packet Error Rate of $S-2-r$ and $r-2-D$ transmission
λ_{S-r} / λ_{r-D}	SINR value of $S-2-r$ and $r-2-D$ transmission
χ_{coop}	Cooperative Success Rate
d_{S-r} / d_{r-D}	Distance among $S-2-r$ and $r-2-D$
β	Path-loss factor
W_{coop}	Overall power consumed in cooperative communication
$\varphi_{coop}^{ns_i}$	Cooperative throughput of network scenario-i
ρ_{S-r} / ρ_{r-D}	Probability of successful packet transmission from $S-2-r$ and $r-2-D$
η_a	Efficiency of amplifier
W_a	Transmission amplifier's energy dissipation
R_{coop}	Data-rate of cooperative communication
E_{coop}	Total cooperative energy consumption
$\mathcal{D}_{coop}^{e2e}$	End-to-End delay for two-hop Cooperative communication
T_{S-r}^{tx} / T_{r-D}^{tx}	Expected directional data transmission time from $S-2-r$ and $r-2-D$
δ_r^{sel}	Relay selection time
δ_O^{tx}	Protocol overhead transmission time

the end-to-end delay ($\mathcal{D}_{coop}^{e2e}$) for cooperative communication for the two-hop path from S to D can be expressed as [32]:

$$\mathcal{D}_{coop}^{e2e} = T_{S-r}^{tx} + T_{r-D}^{tx} + \delta_r^{sel} + \delta_O^{tx} \tag{36}$$

where, T_{S-r}^{tx} and T_{r-D}^{tx} denote the expected directional data transmission time from $S-2-r$ and $r-2-D$, respectively. Again, δ_r^{sel} is the relay selection time and δ_O^{tx} is the protocol overhead transmission time. Hence, the end-to-end delay for two-hop cooperative communication varies based on the four distinct network scenarios of our proposed MAC operation because each of the scenario has different cooperative transmission time and cooperative transmission delay or overhead.

VII. PERFORMANCE EVALUATION

The performance of our proposed CAR MAC protocol is evaluated using simulation experiments. The simulation models of our proposed protocol along with the compared protocols are designed and developed in OMNeT++ simulator [42]. We compared the simulation results of the proposed CAR MAC with the state-of-the-arts non-cooperative MAC and cooperative MAC protocols for network throughput, packet drop rate, energy consumption, end-to-end delay and protocol overhead. Therefore, the simulation results of CAR MAC are compared with IEEE 802.11 [11] and CMD MAC [13] for single-channel omnidirectional communication of non-cooperative MAC protocol and multichannel directional communication of cooperative MAC protocol, respectively. The operational process of a non-cooperative version multichannel directional MAC may have particularly serious effects on protocol performance. Hence, the results of proposed CAR MAC are further compared with non-cooperative multichannel directional NCMD MAC; a non-cooperative edition of CMD MAC where both of the notions of control channel and data channel cooperation are not available.

A. SIMULATION ENVIRONMENT

The parameters we used to configure the simulated environment are given in Table 6. The entire simulation time is 100 seconds where each simulation is carried out for 10 seconds. The average output of 10 simulation runs is estimated as the simulation results.

B. SIMULATION METRICS

To rationalize the performance of our proposed CAR MAC protocol simulation results are analyzed considering the following performance metrics:

- *Throughput:* It is the successful packet transmission rate from source to destination and measured in *Mbps*.
- *Packet Drop Rate (PDR):* It is the ratio between total effectively received packets by a destination and total transmitted data packets by a source in a specific period and estimated in percentage (%).
- *Per Packet Energy Consumption:* It is the average amount of energy consumed to receive a data packet effectively in each simulation run and calculated in Joule (J).
- *End-to-End Delay:* It is the average time passed away to effectively deliver a data packet from a source to its destination and estimated in millisecond (ms).
- *Control Packet Overhead:* It is the number of Bytes in control packets are transmitted during negotiation in the control channel in each simulation run and measured in Bytes.

TABLE 6. Simulation parameters.

Parameter	Value
Simulation Area	$1000 \times 1000\ m^2$
Node Deployment Type	Uniform Random
Number of Nodes deployed	$10 \sim 60$ nodes
Omnidirectional Transmission Range	400 m
Directional Transmission Range	825 m
Number of Data Channels (DC)	5
Number of Control Channel (CC)	1 (Dedicated)
Data-rates for data transmission	1, 2, 5.5, 11 Mbps
Data-rate for control packet	1 Mbps
Data Packet Size	512 Bytes
RTS/CTS/MCTS Length	25 Bytes
VTR/CTR Length	31 Bytes
VTN Length	36 Bytes
RES Length	26 Bytes
ACK Length	5 Bytes
CCA duration	$40\mu s$
SIFS duration	$16\mu s$
Packet Generation Rate	$10 \sim 100$ Pkt/s
Antenna Beamwidth	$15° \sim 90°$
Number of sectors (M)	$2 \sim 8$ per node
Frequency Band	$2.40 \sim 2.48$ GHz
Number of Simulation Runs	10
Total Simulation Time	100 Seconds

C. SIMULATION RESULTS

In this section, we presented the performance comparisons of proposed CAR MAC protocol with IEEE 802.11b [11], CMD MAC [13] and NCMD MAC protocols based on the above mentioned performance metrics.

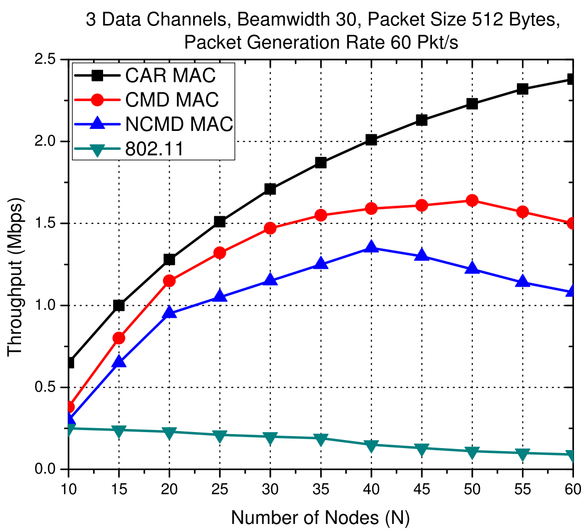

FIGURE 20. Throughput with different node density.

Fig. 20 represents the influence of node density on the throughput of different protocols. It exhibits that with the numeral increment of nodes CAR MAC gains obsessive throughput than CMD MAC and NCMD MAC owing to the fact that when the amount of nodes become greater in amount for CMD and NCMD MAC, the packet drop-rate rises on account of vetos, hidden terminal problems and deafness problems. In contrast, CAR MAC provides higher throughput by eliminating deafness and hidden terminal problem for using both types of cooperation. However, the throughput of traditional IEEE 802.11 MAC protocol decreases linearly because 802.11 is a single-channel omnidirectional MAC protocol. According to this protocol, the collision of data and control packet is proportional to the number of nodes available in a network. While the number of node increases in the network the hidden terminal problem increases and due to arising a lot of hidden terminal problems collisions occur and thus overall network throughput decreases.

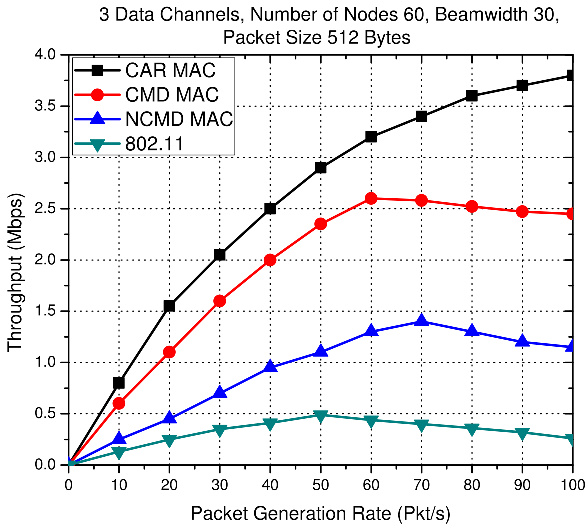

FIGURE 21. Throughput with different traffic load.

The influence of several traffic generation rates on the throughput of different protocols is shown in Fig. 21. Here, the proposed CAR MAC protocol avails superior throughput than all the compared protocols when the packet generation rate increases with time. Initially, the throughput of CMD MAC is proportional to the increase in packet generation rate. However, when the packet generation rate increases near to 50% of the highest packet generation rate of the network, the throughput of CMD MAC decreases because of the packet drop-rate increases due to the vetos for unidirectional multiple packet generation and hidden terminal problems for unidirectional multiple packet reception and deafness problems. The throughput of NCMD MAC is very low in comparison to CAR MAC and CMD MAC because NCMD MAC operates without utilizing any kind of cooperation results in higher packet drop-rate due to hidden terminal problems and deafness problems. IEEE 802.11 achieves nominal throughput since omnidirectional transmission of huge data and control packets in a single-channel results in a collisions due to hidden terminal problems. In contrast, CAR MAC avails superior throughput than CMD, NCMD and IEEE 802.11b

MAC protocols by virtue of data packet relaying. Utilizing cooperative data relaying CAR MAC limits packet loss and results in superior throughput.

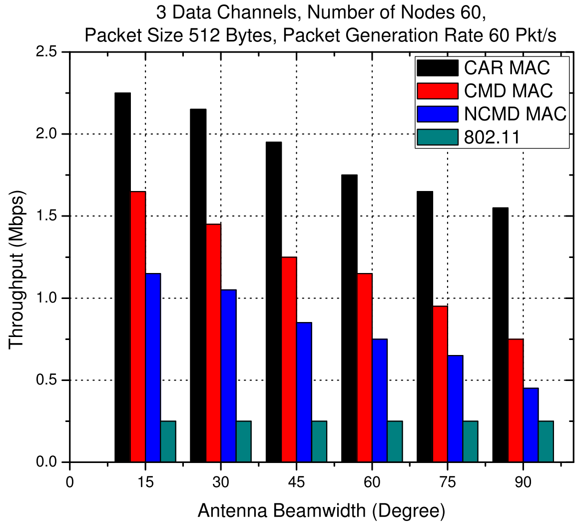

FIGURE 22. **Throughput vs. antenna beamwidth.**

Fig. 22 demonstrates the impact of antenna beamwidth on the throughput of different protocols. When the antenna beamwidth expands, the throughput of compared MAC protocols deduces. A transmission with higher antenna beamwidth covers more area and may collide with the transmissions those intersect in the same or nearer direction and distance. Here, CAR MAC also gains superior throughput for cooperative parallel transmission in the same or different data channels. On the other hand, cooperative data relaying is not supported by CMD MAC and higher antenna beamwidth results in collision and packet drop due to the hidden terminal problems, deafness problems and cooperative vetos in CMD MAC operational principle. In contrast, the overall network throughput of NCMD MAC is lower than CAR MAC and CMD MAC because none of the two types of cooperation is available in NCMD MAC and results in higher collision and packet drop. Finally, directional communication is not supported by IEEE 802.11 MAC protocol. Thus, a static lower throughput value is availed by utilizing the IEEE 802.11 MAC protocol.

In Fig. 23, the relationship between throughput and the numerical quantity of data channels of different protocols. When the numerical quantity of data channel increases, the throughput also increases. In this case, the proposed CAR MAC functions better than CMD, NCMD and IEEE 802.11 MAC protocols. When the number of data channels increases, the cooperative data relaying capability of CAR MAC increases as well. Thus, the overall network throughput of CAR MAC increases due to the increased rate of successful data transmission and CAR MAC outperforms well than CMD MAC and NCMD MAC. In contrast, the IEEE 802.11 MAC protocol operates in a single-channel network environment and performs with much lower throughput

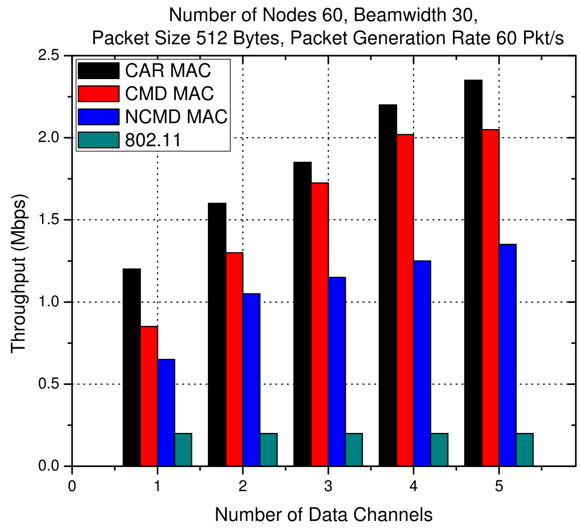

FIGURE 23. **Throughput vs. number of data channels.**

compared to CAR, CMD and NCMD multichannel MAC protocols.

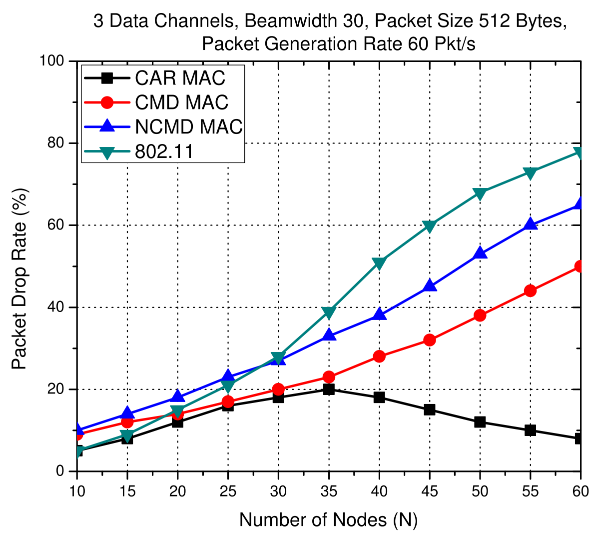

FIGURE 24. **Packer drop rate with different node density.**

Fig. 24 demonstrates the Packer Drop Rate (PDR) considering to the nodes numerical quantity. Initially, the amount of nodes increases the PDR increases as well for all reference MAC protocols. In the case of CAR MAC, when the numerical quantity of nodes increases near about 50% of the maximum amount of available nodes in the network scenario the PDR of CAR MAC decreases due to the increase of available helper node for data relaying. Thus, the CAR MAC ensures least possible PDR than CMD MAC, NCMD and 802.11; because both of the notions of cooperation of CAR MAC increase the transmission reliability and decrease packet loss. However, the PDR of IEEE 802.11 increases over time because 802.11 MAC protocol operates in single-channel with omnidirectional packet transmission. When the number of nodes increases in the network; the data and control packet transmission increases in the single-channel results in a higher collision and thus packet drop rate increases.

Fig. 25 also demonstrates the Packer Drop Rate (PDR) considering the packet generation rate of different protocols. Here, when the packet generation rate increases, the PDR increases as well. Here, in case of a saturated network scenario, the CAR MAC ensures nominal PDR. CAR MAC provides data relaying facility and ensures reliable data transmission in case of huge packet generation. In contrast, the IEEE 802.11 MAC protocol has higher PDR in comparison to CAR, CMD and NCMD MAC protocol. However, the CMD and NCMD MAC protocol have almost the same PDR value and the value is always proportional to packet generation rate. Whereas, the PDR value is always less than the PDR value of IEEE 802.11 and greater than CAR MAC protocol concerning time.

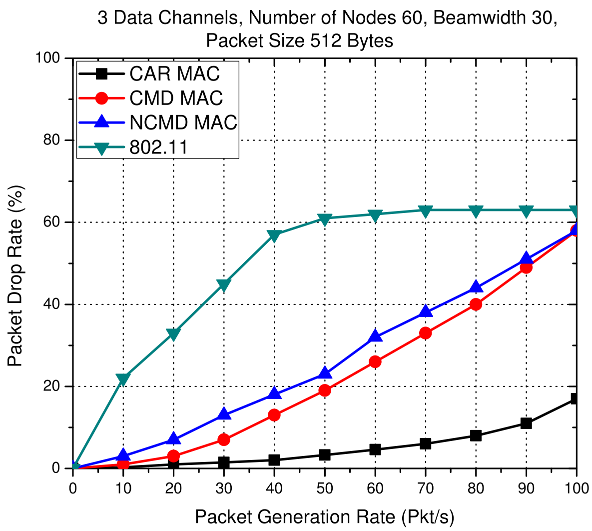

FIGURE 25. **Packer drop rate with different traffic load.**

Fig. 26 demonstrates the energy efficiency of CAR MAC compared to CMD MAC, NCMD MAC and IEEE 802.11 MAC protocols varying the number of deployed nodes of the simulated network environment. Here, the proposed CAR MAC is more energy-efficient than CMD MAC, NCMD MAC and IEEE 802.11 MAC protocols. The reason is that during the simulation period the CAR MAC achieves a higher rate of successful data packet transmission than the compared protocols. Hence, in the CAR MAC protocol, the energy consumption for each data packet transmission is lower. When the node density increases in CAR MAC the energy efficiency increases as well; because the availability of relay nodes increases and ensures the selection of the best relay node. Optimal relay nodes ensure successful data packet transmissions and increase the energy efficiency of the network. Besides, the CMD MAC protocol consumes minimum energy when the number of nodes is 40. When the number of nodes further increases the number of control channel negotiation,

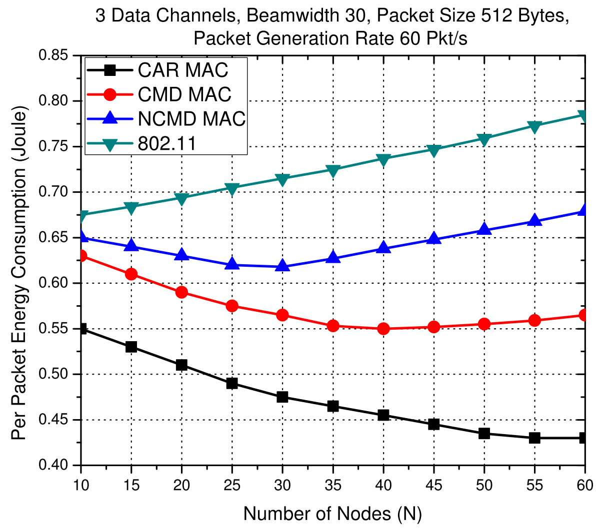

FIGURE 26. **Per packet energy consumption with different node density.**

data packet retransmission also increases due to producing lots of veto frames and results in higher energy consumption per data packet transmission. In contrast, NCMD MAC is lower energy-efficient than CAR MAC and CMD MAC; because the unavailability of cooperation features results in a lower rate of successful data packet transmissions. However, IEEE 802.11 has lower energy efficiency because of its single-channel, omnidirectional and non-cooperative fashion of operation results in higher data packet collision.

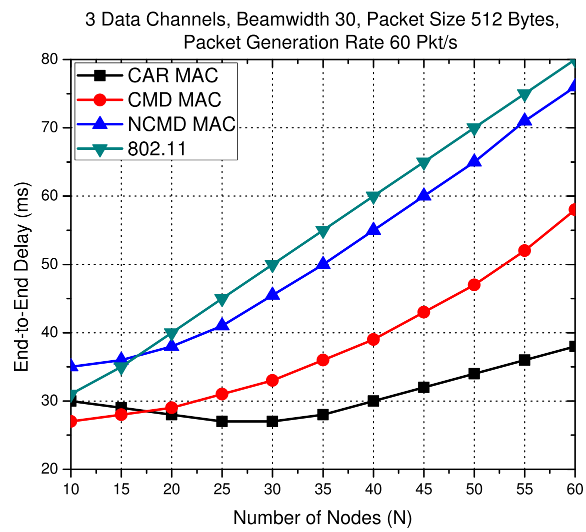

FIGURE 27. **End-to-end delay with different node density.**

Fig. 27 Shows that the average end-to-end delay of CAR MAC is less than the CMD MAC, NCMD MAC and IEEE 802.11 MAC protocols. When the node density increase in CAR MAC protocol the end-to-end delay decreases because the number of optimal relay nodes increases and reduces data packet collision by minimizing deafness and hidden terminal problems. Thus, it results in a lower packet drop rate by the increasing rate of successful data packet transmission with minimum end-to-end delay. CAR MAC has encountered minimum end-to-end delay with 30 numbers of nodes. If further the number of deployed nodes increases, the packet generation rate increases and data packet collision increases as well. Thus, the end-to-end delay of data packet transmission in CAR MAC increases. Initially, the end-to-end delay for CMD MAC is lower than CAR MAC; because less control packet negotiation is required for less number of nodes. However, with the increased number of nodes, great extents of the hidden terminal and deafness problem arise and result in a higher end-to-end delay. Furthermore, the end-to-end delay of NCMD MAC and IEEE 802.11 MAC protocols are almost the same and higher than CAR MAC and CMD MAC; because a great extent of data packet collision occurs due to unavailability of cooperative data transmission and cooperative information sharing as well.

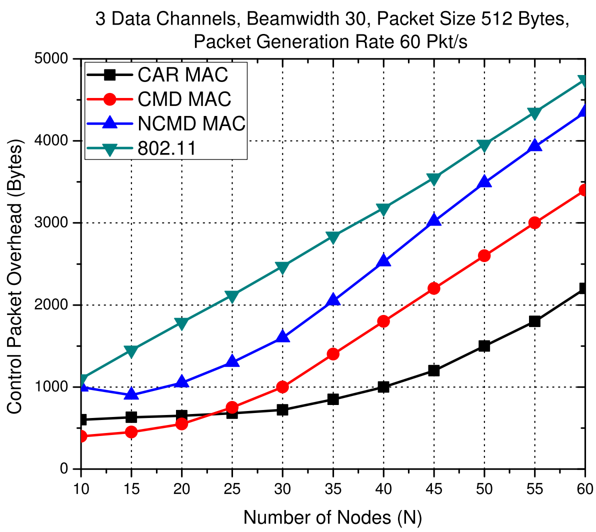

FIGURE 28. Control packet overhead with different node density.

The graph in Fig. 28 represents the comparative efficiency in terms of control packet overhead of different protocols under the different number of node densities over the network. Here, the control packet overhead of protocol operation for CAR MAC is lower than CMD MAC, NCMD MAC and IEEE 802.11 MAC protocols. In the case of CMD MAC, the control packet overhead at the very beginning with a few numbers of nodes is lower than CAR MAC; because at this time CAR MAC exchanges more control packet than CMD MAC for cooperative best relay selection and cooperative data relaying. When the number of node increases in CMD MAC, the deafness and hidden terminal problems increase and result in a huge number of data packet collisions. Hence, data packet retransmissions increase control packet overhead in CMD MAC. The control packet overheads of NCMD MAC are higher than CAR MAC, CMD MAC and lower than IEEE 802.11 MAC protocol. Finally, IEEE 802.11 requires the highest control packet overhead than other compared protocols; because negotiations and data packet transmissions have taken place in a common channel and result in a higher number of collisions and requires maximum control packet overhead for data packet retransmissions.

Finally, considering the above-mentioned dynamic wireless environment simulation results demonstrate that the proposed CAR MAC attains notable improvement in network performances. Such performance improvement obtained 11% to 71% for throughput, 5% to 84% for packet delivery ratio, 13% to 25% for energy consumption, 3% to 35% for end-to-end delay and 10% to 45% for control packet overhead.

VIII. CONCLUSION

The CAR MAC is a Cooperation-based Adaptive and Reliable MAC for multichannel directional wireless IoT networks that employs two types of cooperation jointly; where IoT-enabled wireless nodes are cooperated by neighbor nodes through information sharing through omnidirectional informative control packet exchanging during control channel negotiation and directional data packet relaying in data channel if requires in a dynamic network environment. Hence, the multichannel directional hidden terminal and deafness problems that arise during medium access in a multichannel IoT network environment are avoided through the joint employment of the cooperation strategies and ensures the least data transmission delay and higher network throughput. In addition, smart GPS based neighbor discovery approach is utilized; where, a new direction estimation formula is introduced. Moreover, parallel data transmission in same data channel is achieved through diverse directional communication and ensuring higher throughput. Simulation results show that CAR MAC removes iterative control channel negotiation, minimizes the packet loss, energy consumption, protocol overhead and provide better throughput performance by cooperative data packet relying and parallel transmission.

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