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RESEARCH ARTICLE

Time-Slot Reservation and Channel Switching Using Markovian Model for Multichannel TDMA MAC in VANETs

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ABSTRACT Efficient communication in the intelligent transport system requires the vehicles to transmit safety and non-safety messages timely without any loss. In multi-channel MAC, the attributes of SCH channels are frequency range, frequency limit, power limit, distance covered, and channel performance. Based on these channel properties, messages must be transmitted using the most appropriate channel. Existing multi-channel MAC approaches randomly choose the available SCH channel to transmit the messages. Random selection of the channel leads to over-utilization or under-utilization of channel resources. The channel allocation in the proposed approach reserves the most appropriate SCH and optimizes resource utilization. The proposed variable size TDMA approach for SCH channel allocation considers a large number of contending vehicles with the collision-free allocation of resources. The paper also focuses on reducing the transmission collision and re-usability of the time slot for message transmission. Markovian modeling determines the probability of successfully reserving the time slot and switching to the required SCH. Simulation results prove that the probability of time slot reservation in the required SCH is approximately 0.6 for the proposed approach and approximately 0.2 for other approaches.

INDEX TERMS Multi-channel MAC, WAVE, DSRC, IEEE 802.11p, TDMA, transmission collision.

I. INTRODUCTION

Vehicles communicate using the channel resources for timely delivery of safety and non-safety messages. Vehicles transmit the time-sensitive safety messages and control messages periodically to all the neighboring nodes. Safety message transmission is critical and hence requires a higher transmission frequency. Message transmission requires a minimum frequency of 10 - 50 Hz for highly critical messages [1]. The dedicated short-range communication (DSRC) protocol divides the 5.9 GHz frequency with a bandwidth of 75 MHz into seven channels (1 CCH and 6 SCH) [2]. Initially, vehicles are at the control channel and switch to the service channel to transmit public and private safety and non-safety messages. The authors in [3] have proposed that the vehicles having safety messages transmit them at a higher priority. Switching of the channel is based on the prioritization of the vehicle accessing the channel. Channel resources must be adequately utilized to enhance the performance of the safety message delivery. So it is required to balance the load over the control channel [4]. Four IEEE standard channel switching mechanisms are proposed for CCH and SCH channel switching: a) Continous mechanism for accessing the CCH for complete sync interval, b) Alternating mechanism for accessing CCH and SCH alternatively for half sync intervals, c) Immediate mechanism allow switching of the channel based on the priority of the message to be sent and d) extended mechanisms allow the SCH to be used for an extended period till the full transmission over the SCH is not complete [5], [6]. RSU and OBU transmit WAVE (Wireless Access in Vehicular Environment) service advertisement (WSA) and WAVE service message (WSM) for communication. Safety messages such as traffic signal, curve warning, emergency braking, crash prediction, turning assistance, lane change warning, etc., have higher priority of transmission [1]. The service provider (RSU or Vehicle) defines a basic service

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TABLE 1. DSRC channel [10]–[12].

Channel			Frequency Range	Power Limit	Applications	Frequency Limit	Distance	Channel Performance
Id	Type	Notation Used						
172	SCH	S_2	5.855 - 5.865 GHz	23 dBm	V2V critical public safety applications	10 MHz	100 m	High Availability, Low Latency
175 (174+176)	SCH	S_3	5.865 - 5.885 GHz	33 dBm	Public Safety / Private	20 MHz	400 m	Medium Range SCH
178	CCH	S_1	5.885 - 5.895 GHz	44.8 dBm	Control msg	10 MHz	1000 m	
181 (180+182)	SCH	S_4	5.895 - 5.915 GHz	23 dBm	Public Safety / Private	20 MHz	100 m	Short Range SCH
184	SCH	S_5	5.915 - 5.925 GHz	40 dBm	Public safety (Intersections)	10 MHz	1000 m	High Power, Wide area coordination, Low Interference

set for all the vehicles within its communication range and transmits a periodic WSA consisting of channel information of all the vehicles in BSS [7]. The provider broadcasts this WSA regularly to notify its presence in the network. SCH with the least interference [8] is selected by the provider. Nowadays electric vehicles are gaining popularity and vehicles need to have a charging station where the vehicles can be charged without waiting in a queue. In [9], the author has proposed a token-based algorithm where the vehicles can use the charging station resources based on their tokens.

A. MULTI-CHANNEL DSRC

CCH and SCH channels have 10 MHz of the frequency with different performance parameters such as power, range, distance, latency, interference. [13], [14]. Table 1 provides the categorization of the channels based on frequency, power, distance, and performance. Safety messages and the request for service messages are sent over the control channel (CCH), whereas non-safety messages are transmitted over the service channel (SCH) [15]. Messages must be transmitted using appropriate SCH based on the channel resource requirement for the transmission. Efficient and optimized resource utilization can be achieved by the allocation of required SCH for the message transmission.

B. TIME DIVISION MULTIPLE ACCESS

In TDMA, channel resources are utilized by the nodes based on time. TDMA approach allows the vehicle to dedicatedly access channel resources for message transmission during its allocated time slot. Based on the availability, these time slots are assigned to the nodes to access the channel resources for message transmission. Vehicles transmit the messages during the reserved time slots reducing the occurrence of message collision. Authors [16], [17] have proposed dividing the time frame as variable-sized, fixed-sized, and dynamic sized based on the system's requirements. In this paper, a variable-sized time frame division mechanism is proposed for appropriate SCH channel access. This paper also discusses the successful reservation of time slots and channel switching using the Markovian Model. The paper discusses the solution for handover and collision(access and merging).

C. CONTRIBUTIONS

The proposed approach focuses on the following contributions:

- Allocation of the time slot to the vehicle for the required service channel.
- Improves over-utilization or under-utilization of channel resources.
- Identification of the most appropriate SCH if no time slot is available on the required SCH.
- Successful time slot allocation on the required SCH using Markovian modeling.
- Channel Switching for available time slot using Markovian modelling.

This paper is categorized into different sections. Section II briefs the related approaches proposed by the researchers. Section III defines the Problem Statement. Section IV discusses the approach proposed in this paper. Section V shows the results of the simulation and comparison. The conclusion of the proposed approach is provided in Section VI.

II. RELATED WORK

The authors in [18] have proposed a synchronous multi-channel MAC protocol where the On-Board Unit (OBU) reserves the SCH during CCH for the entire sync interval. In this paper, RSU broadcasts the information to the OBUs and resolves the hidden terminal issue in multi-channel MAC protocol. In [19] paper authors have proposed a multi-channel MAC protocol for efficient message broadcast with high CCH throughput. In APDM [20], priority-based distributed MAC protocol, the duration of the CCH and SCH are dynamically adjusted based on the message transmission probabilities. Protocol AMAC [21] has proposed improvement for the channel access and scheduling mechanism for the MAC layer in IEEE 802.11p/1604.9. If congestion on CCH is very high then the CCH channel is used in the continuous mode. If congestion is moderate over CCH then the CCH channel and SCH channel are used in the alternating mode. With very low congestion over the CCH, vehicles will switch to the SCH channel in immediate mode. In [22], the authors have presented a variable size control channel interval (CCHI) and service channel interval (SCHI) for immediate switching to the CCHI from SCHI on the arrival of the safety message for minimization of the waiting period and improved resource utilization. The authors [23] have proposed a dynamic-sized multi-channel CCH and SCH interval that is adjusted based on the traffic densities. The authors in [14] have presented an adaptive CCH and SCH frame for quick channel accessing and time slot utilization. In RAM protocol [24], RSU finds out the optimal time interval and records the transmission of the safety messages, and considers a cooperative relaying mechanism for message re-transmission. The TDMA based VCAR-MAC [25] protocol provides efficient CCH allocation for safety message delivery and multi-channel coordination in SCH to provide adaptive length SCH for better channel utilization. In [26] the vehicle with sequence number 1 uses the time slot for the message broadcast, while other vehicles will wait for their sequence. In [27] vehicles form cluster and reserve the time slot in multi-channel MAC protocol for timely delivery of safety and non-safety messages. Slotted TDMA multi-channel MAC is used [28] for the communication in an overlapped vehicular network. TM-MAC [29] use variable size multi-channel TDMA for the timely delivery of safety messages and reduces the occurrence of transmission collision. For V2V (vehicle-to-vehicle) communication, vehicles are clustered [30] to use the multi-channel TDMA MAC combined with CSMA efficiently and fairly. Authors [31] have proposed a geographic location-based time slot reservation mechanism for efficient usage of the SCH channel. In [32], the disjoint time slots for multi-channel MAC are allocated to the vehicles moving in a different direction. Adaptive distributed [14] MAC transfers safety, entertainment, and service messages using point-to-point communication. In Adaptive Multi-channel [11] MAC, both CCH and SCH channels are analyzed for a sync interval of 100 ms for congestion. In POCA-C [3] the time slot over SCH is allocated during the CCH interval based on the number of primary providers requiring the SCH for safety message transmission. All the secondary providers negotiate for the allocation of the time slot over SCH for non-safety message transmission. In POCA-C the primary provider broadcasts the information of SCH it will use for message transmission. In POCA-D [3] the secondary providers do not negotiate for the reservation of the time slot. In [33], the author has used the markovian model to identify the channel state during the message transmission. Here the states are considered as good or bad based on the channel quality during the allocated time slot. In [34], the author has proposed a hybrid multichannel MAC protocol that uses TDMA and CSMA during the CCH to decide the timeslot length based on traffic density. The markovian model is used to identify the number of time slots in SCH under high traffic density. Markovian model is used in [35] for an adaptive selection of the back-off period for the contention window in case of high density traffic. Vehicles initially choose an optimal contention window size and further update the size. Adaptive size helps in confirm transmission of the latest messages also. In [36], the Hidden Markov model is used for accident prediction in urban areas using the correlation between latent variables and observations. The latent variable is considered as the risk of crash and observations are velocity, weather, location, density, and driver's fatigue. In [37], a TDMA approach is proposed for resource utilization based on the capture effect and optimal frame length set by RSU. A discrete Markov chain is used by the author to analyze the capture effect on channel utilization. The existing TDMA for multi-channel MAC protocol does not focus on allocating the time slot on the SCH channel based on the requirement of the messages to be transmitted. Due to the random selection of the available SCH, an inappropriate channel is selected to transmit a particular type of message, leading to over-utilization or unavailability of the resources leading to either wastage of resources or message loss, respectively. The proposed approach reserves the available time slot from the best suitable SCH for the message delivery, leading to proper channel utilization and reducing transmission collision by reusing the time slot based on the message's requirement.

III. PROBLEM STATEMENT

Fixed-size channel allocation may lead to insufficient channel resources for a large number of message transmissions or wastage of the channel resources for fewer message transmissions. Restricted availability of channel resources leads to improper resource distribution. High-priority messages are lost due to improper resource allocation. Time-based allocation of the channel resources allows the re-usability of resources during the reserved time slot and doesn't guarantee the allocation of the appropriate SCH channel. Based on the frequency of service channel usage, the size of the time frame for a particular channel must be defined. So, there is a requirement to design a variable size time slot for the service channels. The proposed approach provides a variable-sized TDMA for the SCH channel based on the message density, priority, and type. Based on the message priority, messages are transmitted using the required SCH channel or SCH channel having similar properties if the required SCH channel is busy. So that high-priority messages are not lost due to insufficient channel resources. The allocated time slot for every SCH channel is reused by other vehicles. Multi-channel hidden terminal leads to the inefficient reuse of the time slot. The proposed approach also focuses on efficient re-usability of the channel resources without merging or accessing collision.

IV. PROPOSED APPROACH

A. SYSTEM MODEL

Roadside Unit (RSU) and vehicles broadcast WSA_{V_a} at regular intervals in the network. The vehicles accepting WSA_{V_a} form the BSS to communicate with the provider. The communication range of RSU C_{RSU}, is up to 3 km [81] whereas vehicles can communicate to the other vehicles belongs to N_{OH} to avoid interference. In fig. 1, for V2I (vehicle-to-infrastructure) communication, RSU acts as a provider and broadcasts the WSA_{RSU} to all the vehicles within C_{RSU}. On receiving the WSA_{RSU}, vehicles get the information of the

RSU they are registered to and the allocated time slots set per SCH. During V2V communication, the provider vehicle V_a broadcasts the WSA_{V_a} to the vehicles that belongs to N_{OH}. The vehicle V_b that is ready to communicate with the provider vehicle V_a accepts the membership to the BSS. BSS may overlap based on the vehicle acting as a provider. For a stochastic model, based on the current state of the system the probability of the next state can be calculated for which the markovian model proves to be the best. In the proposed approach, based on the number of time slots already reserved in the required SCH we calculate the probability of allocation of the time slot for SCH. Similarly based on the current channel usage the probability of switching to the next appropriate channel is also calculated. For this purpose in the proposed approach the Markov model [34], [35], [82], [83] [84] is used to determine the probability of successful reservation of the time slot by the contending nodes on required SCH. Also, the Markov model is used to determine the SCH channel switching if there is no time slot available on the required SCH. The symbols used in the proposed approach are mentioned in the table. 2.

TABLE 2. Symbols used in proposed approach.

Symbol	Definition
V_a	Source node in communication
V_b	Destination node in communication
V_c	Intermediate node in communication
l_{syn}	Length of Sync interval
C_{RSU}	Coverage range of RSU
C_{node}	Coverage range of the nodes
N_{OH}	nodes within one hop communication range
N_{TH}	nodes within two hop communication range
WSA_{V_a}	WAVE Service Advertisement message generated by V_a
M_{SCH_x}	Message containing information of required Service channel x
M	Message to transmit from V_a to V_b
S_1	Control channel CCH
S_2	Service channel SCH 172
S_3	Service channel SCH 175
S_4	Service channel SCH 181
S_5	Service channel SCH 184
SA	Set of available time slots
SB	Set of busy time slots
S_xA	Service channel x is available
S_xB	Service channel x is busy
D_L	Set of vehicles moving in left direction
D_R	Set of vehicles moving in right direction
Type1	Messages transmitted using SCH 175
Type2	Messages transmitted using SCH 181
Type3	Messages transmitted using SCH 172 or 181
Type4	Messages transmitted using SCH 175 or 184
T	Total number of time slots
t_{SCH_x}	Time slot required on the service channel x
X	$X = T - t_{SCH_x}$: time slots available but not in the required channel
Z	Number of time slots required $Z >$ Total time slot T
T_{iSCH_x}	i^{th} time slot reserved in required service channel x
T_{jSCH_y}	j^{th} time slot reserved in next most appropriate service channel y
p_{ij}	Probability of moving from current state 'i' to next state 'j'
p_{ii}	Probability of current and next state 'i' to be same

B. MULTI-CHANNEL CO-ORDINATION

Contention-based, CSMA is used during CCHI and contention-free TDMA is used during SCHI. For multi-channel coordination, each vehicle and RSU have two transceivers, amongst them one is synchronized to receive the messages and the other is synchronized to transmit the messages. On arrival, the vehicle senses the availability of the CCH channel and if the channel is free then it broadcasts the WSA_{V_a} message to the N_{OH} that further forwards the WSA_{V_a} to the nearby RSU. WSA_{V_a} sent by the vehicles consist of M_{SCH_x}. Initially, all the vehicles remain tuned to CCH. During CCH all the control messages, periodic WSA, and the high priority of the safety messages are transmitted. The vehicles switch to SCH for the public and private safety message transmission. Channel 172 has high availability and low latency and is used for V2V communication for a short range. For sending public safety or private messages over a medium range, SCH 175 is appropriate. Public safety and private messages should be sent using channel 181 to the short communication range. Messages can be sent to a wider distance nodes using the SCH 184 with a higher power of 40 dBm. These channel properties make every channel unique and they must be used according to their properties for the maximum utilization and availability of the channel resources. Messages are evaluated based on the range, distance, power, and channels required for transmission. Table 3 summarizes the details of the different types of public and private safety messages transmitted among the vehicles. These messages are categorized as Type 1, Type 2, Type 3, and Type 4 messages based on the SCH channel required for their transmission. Due to different channel properties, an approach is required to select the most appropriate channel to transmit the message. Transmission of the messages using the appropriate channel guarantees optimized utilization of the resources. Type 1 is the public safety and private messages that have to be sent to medium distant nodes or RSU that are within the 400 m range so SCH 175 should be utilized for these messages. Since these messages require high transmission power so they cannot be sent using SCH 172 or 181. Using SCH 184 will lead to over-utilization of resources. Type 2 are public safety or private messages that are transmitted to the short-range nodes within 100 m distance so less power is required for their transmission. So, the most appropriate channel to transmit the Type 2 messages is SCH 181. Using SCH 172 will restrict the transmission to the V2V communication so it is avoided and using any other channel leads to over-utilization of resources. Safety and private messages for the V2V communication require less power and frequency due to the point-to-point communication between nearby nodes. These messages have to be transmitted to the short-range nodes within 100 m and power required is less than 23 dBm are categorized as Type 3 messages and they should be transmitted using SCH 172 or 181. Transmission of Type 3 messages using any other SCH channel will lead to over-utilization of resources. Type 4 is that category of messages those have to be transmitted to long distances of 300 m to 1000 m, so the channel that must be used for transmission is SCH 175. In the case of intersections, the required SCH is 184. So the most appropriate channel for

TABLE 3. Allocation of SCH channel for public/private messages.

Message	Range	Distance (in m)	Power Limit (in dBm)		Message Type	
			For RSU	For OBU	For RSU	For OBU
Public Messages						
Approaching Vehicle Warning [38]	Long	300 - 1000	33 - 44.8	23 - 44.8	Type 4	Type 4
Emergency Vehicle Message [39] [40]	Long	300 - 1000	33 - 44.8	23 - 44.8	Type 4	Type 4
Road Conditions [41]	Extended	90 - 335	23 - 33	10 - 23	Type 1	Type 3
Low Bridge Warning [42]	Medium	0 - 90	10 - 23	10	Type 2	Type 3
Working Area Warning [43] [44]	Extended	90 - 335	10 - 23	10	Type 1	Type 3
Imminent Collision Warning [45] [46]	Extended	90 - 335	23 - 33	10 - 23	Type 1	Type 3
Speed limit at Curve Warning [47]	Extended	90 - 335	23 - 33	10 - 23	Type 1	Type 3
Traffic Light Assistance [48] [49]	Extended	90 - 335	23 - 33	10 - 23	Type 1	Type 3
Collision Warning at Intersection [50]	Extended	90 - 335	23 - 33	10 - 23	Type 1	Type 3
Collision Warning for Highways [51]	Extended	90 - 335	23 - 33	10 - 23	Type 1	Type 3
Cooperative Collision Warning [52]	Extended	90 - 335	23 - 33	10 - 23	Type 1	Type 3
Speed Advisory for Green Light [53] [54]	Long	300 - 1000	33 - 44.8	23 - 44.8	Type 4	Type 4
Cooperative Platooning [55]	Extended	90 - 335	23 - 33	10 - 23	Type 1	Type 3
Cooperative Cruise Control [56] [57] [58]	Extended	90 - 335	23 - 33	10 - 23	Type 1	Type 3
Probe Data Collection [59]	Extended	90 - 335	23 - 33	10 - 23	Type 1	Type 3
Probe Data Collection (Infrastructure Based) [59]	Short	0 - 15	10	10	Type 2	Type 3
Toll Payment [60]	Short, Medium	0 - 15 - 90	10 - 23	10	Type 2	Type 3
Traffic Details [61] [62] [63]	Short	0 - 15	10	10	Type 2	Type 3
Data Transfer for Transit Vehicles [64]	Medium	0 - 90	10 - 23	10	Type 2	Type 3
Signal Priority of Transit Vehicles [64]	Long	300 - 1000	33 - 44.8	23 - 44.8	Type 4	Type 4
Emergency Vehicle Video Relay [65]	Extended	0 - 90	23 - 33	10 - 23	Type 1	Type 3
Mainline Screening [66]	Medium	0 - 90	10 - 23	10	Type 2	Type 3
Border Clearance [67]	Medium	0 - 90	10 - 23	10	Type 2	Type 3
On-board Safety Data Transfer [68]	Medium	0 - 90	10 - 23	10	Type 2	Type 3
Inspection of Vehicle Safety [68]	Medium	0 - 90	10 - 23	10	Type 2	Type 3
Daily Logs of Driver [69]	Medium	0 - 90	10 - 23	10	Type 2	Type 3
Private Messages						
Access Control [70]	Short	0 - 15	10	10	Type 2	Type 2
Payment at Parking lot [71]	Short	0 - 15	10	10	Type 2	Type 2
Fuel Information [72]	Short, Medium	0 - 15 - 90	10 - 23	10	Type 2	Type 2
Planning and Guidance of Enhanced Route [73] [74]	Under Investigation	-				
Unique CVO fleet Management [75]	Medium	0 - 90	10 - 23	10	Type 2	Type 2
Transit Vehicles [64]	Medium	0 - 90	10 - 23	10	Type 2	Type 2
Refueling of Transit Vehicles [64]	Medium	0 - 90	10 - 23	10	Type 2	Type 2
Fuel Monitoring [72] [76] [77]	Medium	0 - 90	10 - 23	10	Type 2	Type 2
Payment at Drive-thru [78]	Short	0 - 15	10	10	Type 2	Type 2
Locomotive Data Transfer [79]	Medium	0 - 90	10 - 23	10	Type 2	Type 2
CVO Data Transfer [75]	Medium	0 - 90	10 - 23	10	Type 2	Type 2
Rental Car [80]	Short	0 - 15	10	10	Type 2	Type 2

Required Channels: *Type1 → SCH 175, Type2 → SCH 181, Type3 → SCH 172 or 181, Type4 → SCH 175 or 184*
Range: *Short → 0 - 15, Medium → 0 - 90, Extended → 90 - 335, Long → 300 - 1000*

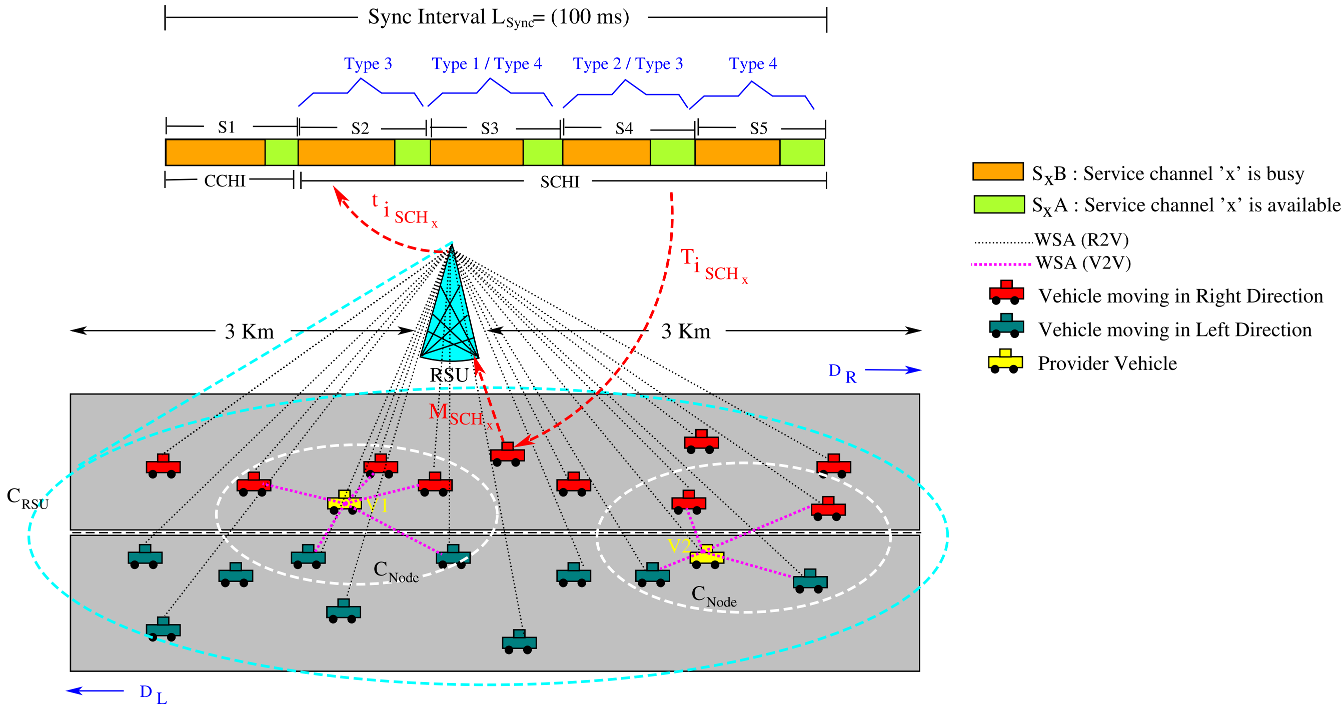

FIGURE 1. Channel Allocation for Vehicles in Proposed Approach.

transmission of Type 4 messages is SCH 175 or SCH 184. All these types of messages are transmitted frequently and massively. Allocating time slot for any other SCH channel does not guarantee sufficient resources leading to message drop. Also, messages transmitted using random SCH lead to over-utilization or under-utilization of the resources. Type 2 messages are maximum in number, whereas, Type 4 messages are the most diminutive. So, the usage of SCH 181 is maximum, and SCH 184 is minimum. Hence, the variable size time frame must be dedicated for the SCH channel. Based on the number of messages, channel properties, and usage, we have proposed a variable-sized time frame for TDMA multi-channel MAC. Considering different types of messages mentioned in table 3 the maximum number of messages is under Type 2, so the size of the time frame for SCH 181 is large, and the number of messages under Type 4 is the minimum, so the size of the time frame for SCH 184 is small. Number of Type 1 and Type 3 messages are approximately equal; hence the size of the time frame for SCH 172 and SCH 175 are considered almost the same.

C. TIME SLOT ALLOCATION FOR REQUIRED CHANNEL

During CCH, RSU transmits the control messages, WSA_{RSU} and safety messages regularly. Whenever a vehicle V_a enters C_{RSU} during CCH, V_a senses the CCH to be idle and transmits the WSA_{V_a} immediately if the channel is idle otherwise, the vehicle waits for the channel to be free. WSA is transmitted by the provider (RSU/vehicle) periodically after a regular interval to notify its presence. OBU on the vehicles determines the channel required based on the message type and broadcast the same in the WSA_{V_a} as M_{SCH_x}. On receiving M_{SCH_x}, RSU checks the availability of time slot t_{SCH_x} and notifies the vehicles about the allocated time slots T_{iSCH_x} through the WSA_{RSU} transmission. If all the time slots for SCH_x are already reserved, then the time slot T_{jSCH_y} is allocated. If no time slot is available in any SCH then the vehicle will reuse the time slot allocated to the vehicle $\epsilon\ N_{TH}$. Otherwise, the vehicle waits for the availability of the time slot. Allocation of the time slot to vehicles on the required SCH is explained in algo. 1. Total time is divided into variable-sized time frames for SCH channels as shown in fig. 2. First-time slots in every SCH are reserved for the RSU for transmission of the control messages, safety messages, WSM, and periodic WSA. During SCH, vehicles use the required SCH channel based on the allocated time slot T_{iSCH_x}. Vehicle releases the allocated T_{iSCH_x} after successful transmission of all the messages and notifies the same to the RSU.

1) TIME SLOT SYNCHRONIZATION

Each vehicle is equipped with an OBU having a unique MAC identifier and a GPS device to provide a universal time for synchronization with other vehicles in its communication range. The length of a sync interval l_{syn} is 100 ms, which is further divided into variable-length frames for CCH and SCH. Guard interval of 1 ms is present for switching among the channels to provide synchronization of the resources and control transmission. The time frame size for the SCH is variable based on the number of messages to be transmitted as shown in Fig. 2.

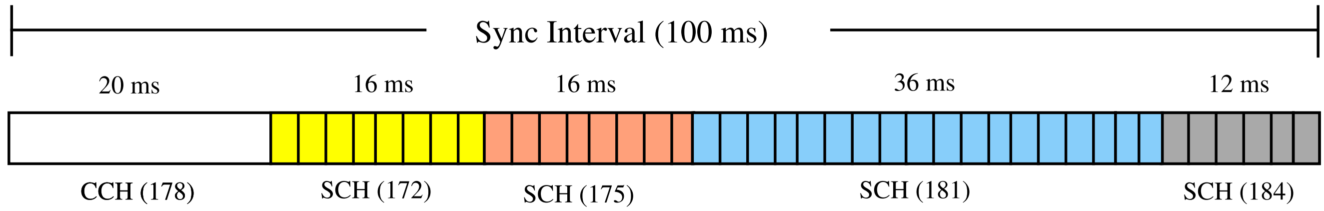

FIGURE 2. Time slot allocation per SCH.

Algorithm 1 Function for Time Slot Allocation (Markovian Model)

Input: M_{SCH_x}
Function `TimeSlotAllocation(`M_{SCH_x}`)`
RSU determines required SCH from M_{SCH_x}
if T_{iSCH_x} *is available* **then**
    RSU allocates T_{iSCH_x} to V_a with p_{mn} as eq. (4)
    allocated_TS = T_{iSCH_x}
else
    if T_{jSCH_y} *is available* **then**
        RSU allocates T_{jSCH_y} to V_a with p_{mn} as eq. (4)
        allocated_TS = T_{jSCH_y}
    else
        allocated_TS = TimeSlotReuse();
    end
end
return *allocated_TS*
Function End
Output: *allocated_TS*

Algorithm 2 Function for Re-Usability of TS

Input: V_a and V_b requesting T_{iSCH_x}
Function `TimeSlotReuse()`
while $x \epsilon T$ *and* $x \epsilon SB$ **do**
    if V_a *and* $V_b \notin N_{TH}$ **then**
        if *(*$V_a \epsilon D_L$ *and* $V_b \epsilon D_R$*) and (*V_a *and* V_b *are moving away from each other)* **then**
            V_a and V_b can reuse T_{iSCH_x}
            TS_reuse = T_{iSCH_x}
        else
            if *Speed*$(V_a) >$ *Speed*(V_b) *and* V_a *is moving ahead of* V_b **then**
                V_a and V_b can reuse T_{iSCH_x}
                TS_reuse = T_{iSCH_x}
            else
                V_v = SelectVictimNode();
                V_v release T_{iSCH_x}
                TS_reuse = T_{iSCH_x}
            end
        end
    else
        RSU select victim node V_v to release T_{iSCH_x}
        TS_reuse = T_{iSCH_x}
    end
end
return *TS_reuse*
Function End
Output: T_{iSCH_x}

2) RE-USABILITY OF TIME SLOT

If T_{iSCH_x} is not available ∀ i, and T_{jSCH_y} is not available ∀ j, then there is a requirement to reuse the already reserved time slots. RSU allows the reuse of the time slot T_{iSCH_x} to V_a which is already allocated to the vehicle V_b, beyond the two-hop distance range. For re-usability of T_{iSCH_x} the following conditions must be satisfied: a) if V_a and V_b are moving in different directions, away from each other, then V_a can reuse the time slot allocated to V_b. b) if V_a and V_b are moving in the same direction, however, the speed of the vehicle ahead is greater than vehicle moving behind then the V_a can reuse the time slot of V_b as given in algo. 2.

3) SELECTION OF VICTIM NODE BY RSU

RSU selects the victim node V_v, among contending nodes V_a and V_b, with the highest probability of getting out of the RSU range earlier. Node consuming least time to hand-over the RSU range is selected as V_v. V_v is notified to release the acquired T_{iSCH_x} as shown in algo. 3.

4) MARKOV MODEL FOR RESERVATION OF TIME SLOTS

Markov modeling of the proposed approach for time slot reservation is done to find out the probability of successful reservation of the time slot on the required SCH channel. Different cases considered are: a) time slot for required SCH are available, b) time slots for required SCH are not available (time slot of other SCH may be used), c) number of contenting nodes is larger than the total number of available time slots, i.e. waiting condition. Markov model for successful reservation of time slot is shown in fig. 3. Let, Z be total number of contending nodes for a specific channel, T be total number of time slots in a frame, and t_{SCH_x} be number of time slots for x^{th} channel in a frame. The probability of the n contending nodes to acquire a time slot in case m nodes have already acquired the time slot is given as p_{mn}:

$$p_{mn} = \begin{cases} \dfrac{N(j, Z-j+1, t-j+1)}{(Z-j+1)^{(t-j+1)}}, & \forall j < t \\ \dfrac{N(i, Z-i+1, T-i+1)}{(Z-i+1)^{(T-i+1)}}, & \forall t < i < T \\ 1, & \forall T < X \\ 0, & Otherwise \end{cases} \quad (1)$$

where, $j, i \epsilon m$ and $Z-j+1, Z-i+1 \epsilon n$.

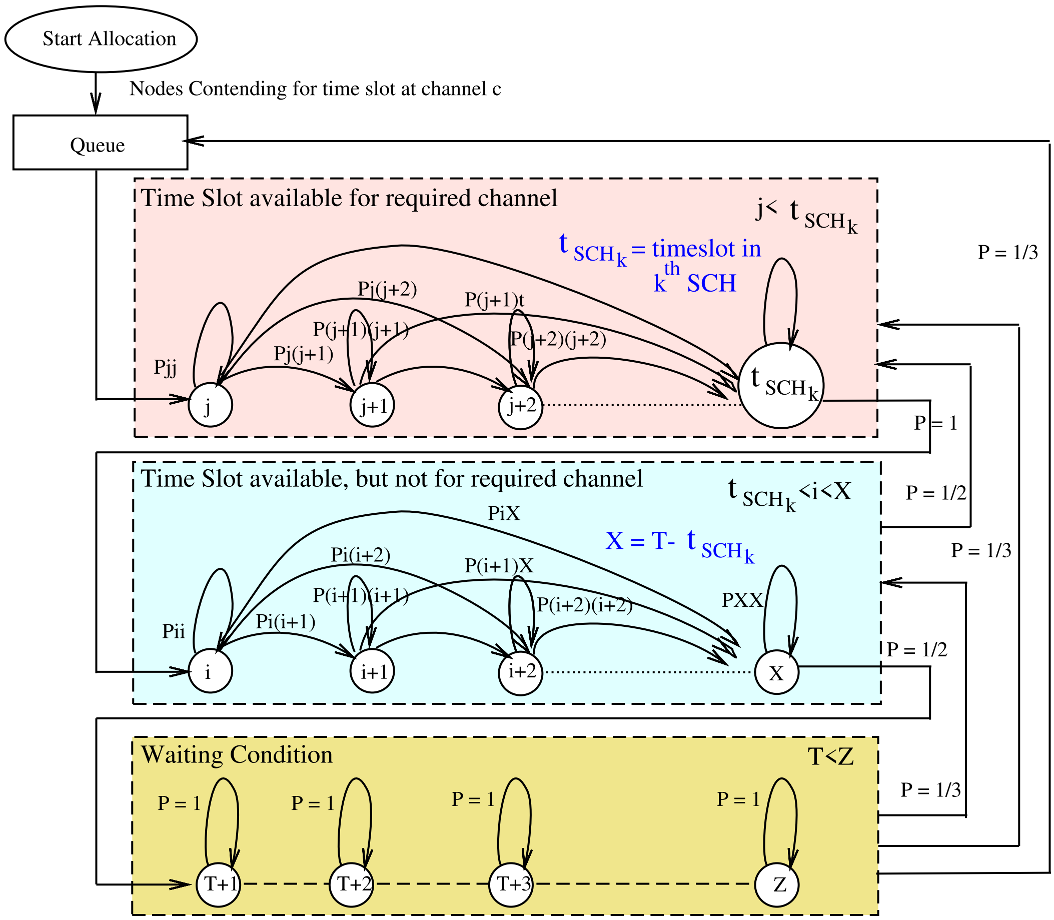

FIGURE 3. Markov Model for Successful Reservation of Time Slot.

Algorithm 3 Function for Selecting Victim Node

Input: V_a, V_b with T_{iSCH_x}
Function `SelectVictimNode()`
if V_a *moves away* C_{RSU} **then**
  $V_v = V_a$
  T_{iSCH_x} allocated to V_b
else
  $V_v = V_b$
  T_{iSCH_x} allocated to V_a
end
MessageTransmission(WSA_{RSU});
return V_v
Function End
Output: V_v

$\forall\, j \mid j \in Z$ contenting nodes for a specific channel are less than the available time slots t_{SCH_x} for the required x^{th} SCH channel, $\forall\ i \mid i \in Z$ contenting nodes for a specific channel are more than the available time slots t_{SCH_x} for the required x^{th} SCH channel but less than the available total time slot T i.e. time slot are available in the remaining SCH channel.

Let b be the total contending nodes and c be the available time slots. So, $N(a, b, c)$ in eq.(1) is the number of ways in which $'a'$ contending nodes acquire $t \,\epsilon\, c$ for the required SCH channel. If the number of contending nodes is greater than the total available time slots then the nodes remain to wait with probability 1. In case if there is no time slot available, then the node waits for the availability of the time slot with a probability $1/3$. Time slot can become available in a required channel or the channel having similar properties. In case the time slots are not available in any SCH channel then the vehicle waits in the queue. If all the time slots for the required channel are occupied, then the vehicle reserves the time slot available for the next appropriate channel with a probability 1. If there is no available time slot then the vehicle can move to the waiting state with a probability $1/2$.

$N(j, Z-j+1, t-j+1)$ is calculated as:

$$N(j, Z-j+1, t-j+1) = {}^{t-j+1}C_{Z-j+1} = \frac{(t-j+1)!}{(Z-j+1)!(t-Z)!} \quad (2)$$

Similarly, $N(i, Z-i+1, T-i+1)$ is calculated as:

$$N(i, Z-i+1, T-i+1) = {}^{T-i+1}C_{Z-i+1} = \frac{(T-i+1)!}{(Z-i+1)!(T-Z)!} \quad (3)$$

By inserting eq. (2) and (3) in (1) we get:

$$p_{mn} = \begin{cases} \dfrac{(t-j+1)!}{(Z-j+1)!(t-Z)!(Z-j+1)^{(t-j+1)}}, & \forall j < t \\ \dfrac{(T-i+1)!}{(Z-i+1)!(T-Z)!(Z-i+1)^{(T-i+1)}}, & \forall t < i < T \\ 1, & \forall T < X \\ 0, & \forall Otherwise \end{cases} \quad (4)$$

where, $j, i \epsilon m$ and $Z-j+1, Z-i+1 \epsilon n$

D. MESSAGE TRANSMISSION

Message transmission in the proposed approach considers WSA, safety, and non-safety private and public messages. Message transmission is done following the algorithm 4.

1) WSA AND SAFETY MESSAGE TRANSMISSION FROM RSU TO VEHICLE

RSU broadcasts the WSA_{RSU} to all the vehicles. RSU also transmits the safety message to the vehicle to notify any kind of emergency. Safety messages are sent directly to the vehicles within C_{RSU}.

2) WSA TRANSMISSION FROM VEHICLE TO RSU

Vehicle V_a broadcast the WSA_{Va} to the N_{OH}. Transmission of the WSA_{Va} to RSU is required to notify the presence of V_a in the C_{RSU}. If the RSU is a one-hop range apart from V_a then the broadcast is received by the RSU directly. Otherwise, WSA_{Va} is relayed by the intermediate nodes for transmission to the RSU.

3) SAFETY MESSAGE TRANSMISSION FROM VEHICLE TO VEHICLE

If the source node V_a and destination node V_b are in N_{OH} then V_a transmits the safety message directly to V_b. Otherwise, V_a relay the message to the intermediate nodes(co-operative node) for relaying the message to V_b. RSU can also act as a cooperative node in a case V_a is near to RSU and far away from V_b. The involvement of RSU in the set of cooperative nodes reduces the number of hops from source to destination and hence improves performance.

E. CHANNEL SWITCHING

For transmission of the message, the vehicle has to check the requirement of the SCH, and if the vehicle V_a is tuned to the required SCH, then the message is sent directly; otherwise, channel switching is needed. The vehicle checks for the reserved time slot t_{iSCH_x} for the required SCH x. If t_{iSCH_x} is allocated to the vehicle, then the vehicle switches to SCH x and transmits the message during the allocated t_{iSCH_x}. Otherwise, the vehicle sends the WSA_{V_a} consisting of M_{SCH_x} to the RSU for allocation of the time slot. During message transmission, channel SCH 175 and 184 are used interchangeably.

Algorithm 4 Function for Message Transmission

```
Input: MSG Function
MessageTransmission(MSG)
if MSG == WSA_Va then
    V_a broadcast MSG to N_OH
    MSG is further relayed to RSU
    V_a registers itself to RSU
    RSU extracts M_SCHx from MSG
    TimeSlotAllocation(M_SCHx);
    Msg_Status = "Success"
else
    if MSG == WSA_RSU then
        RSU broadcasts MSG to the vehicles ϵ C_RSU
        Msg_Status = "Success"
    else
        if MSG == M then
            if V_a & V_b ϵ N_OH then
                V_a transmits MSG directly to V_b
                Msg_Status = "Success"
            else
                if V_a & RSU ϵ N_OH then
                    V_a transmits MSG to RSU
                    RSU transmits MSG to V_b
                    Msg_Status = "Success"
                else
                    if V_c == available then
                        V_a transmit MSG to V_c that relay
                         MSG to V_b
                        Msg_Status = "Success"
                    else
                        Msg_Status = "Failure"
                    end
                end
            end
        end
    end
end
return Msg_Status
Function End
Output: Message Transmission Successful or Failure
```

If the time slot for any of these channels is allocated, the vehicle can directly send the message. Also, channel SCH 172 is used if SCH 181 is busy. So, if there is no time slot allocated for SCH 181, then the message transmission is done using the time slot for SCH 172. If there is no time slot available for any of the SCH, then the vehicle must wait for the time slot to be released by any other vehicle.

1) MARKOV MODEL FOR CHANNEL SWITCHING

Markov modeling of the proposed approach is done to find the probability of switching from CCH or currently synced SCH to required SCH. The switching of the channel is represented using the Markov model as shown in fig. 4. State S_1 represents control channel CCH. For the SCH channels index

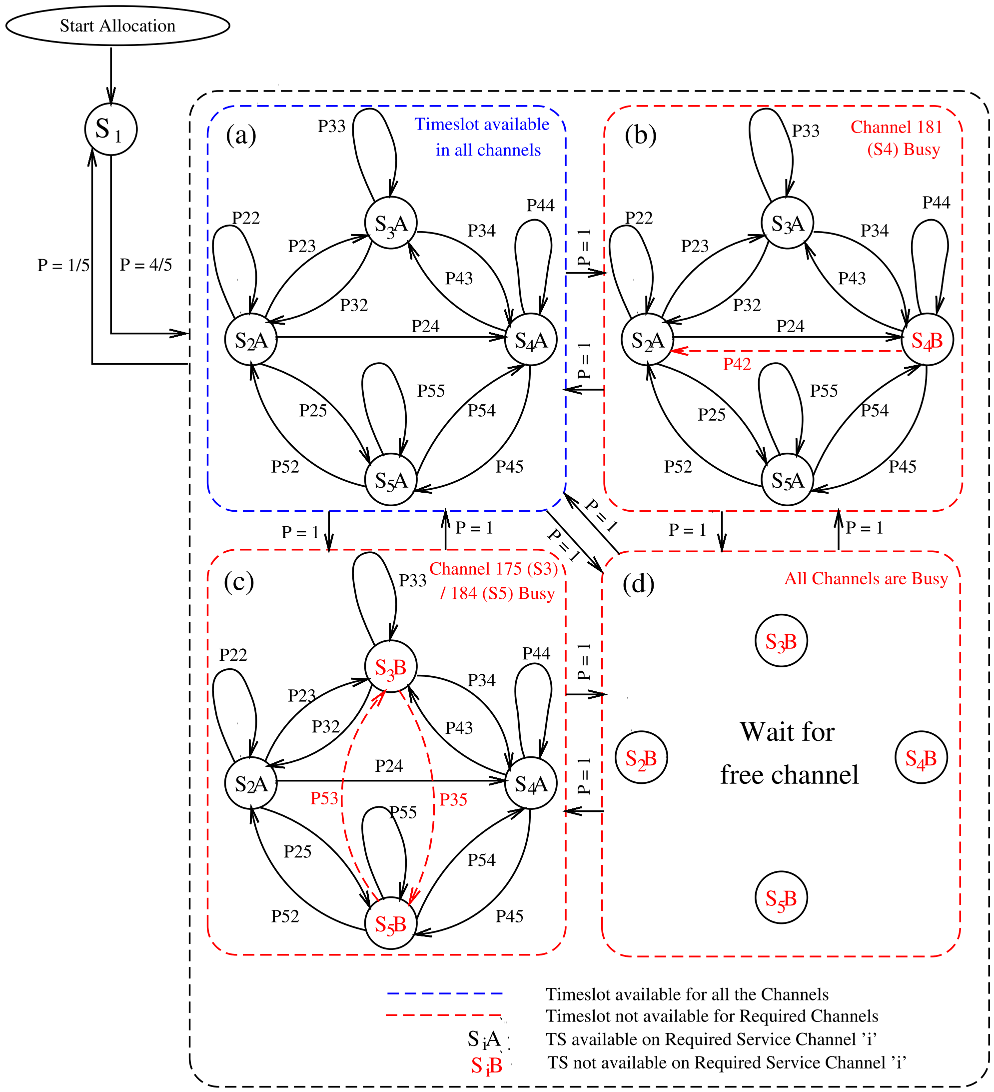

FIGURE 4. **Markov model for channel switching (a) Time slots in all SCH channels available (b) SCH 181 Busy (c) SCH 175 or 184 Busy (d) All SCH channels Busy.**

$i = 2, 3, 4$ and 5 represents the service channel 172, 175, 181 and 184 respectively. State S_iA represents that the i^{th} SCH channel is available. S_iB represents that the i^{th} SCH channel is busy. The probability of switching from one channel to another depends on the type of message to be transmitted. Suppose time slots in all the channels are available, then vehicles reserve the time slot in the required SCH channel for message transmission. This scenario is represented in part (a) of fig. 4. Features of SCH channel 172 is similar to 181, and 175 is similar to 184, so they can be used interchangeably. If all the time slots in channel 181 are busy and time slots in SCH 172 are available, then messages for SCH 181 also are transmitted using SCH 172 as represented in part (b) of 4. Similarly, channels 175 and 184 are used interchangeably if all the time slots for channel amongst them are busy and for other are available as represented in part (c) of fig. 4. Suppose, all the time slots for all the channels are busy then the message cannot be transmitted and wait for the time slot on the required SCH channel to be free as illustrated in part (d) of fig. 4.

$$p_{ij} = \begin{cases} \frac{4}{5}, \ for\ Switching\ CCH\ to\ SCH \\ \frac{1}{5}, \ for\ Switching\ SCH\ to\ CCH \end{cases} \tag{5}$$

The probability of switching of the control and service channel is represented in eq. 5. Suppose there is a total M number of messages to be transmitted among which q number of messages are already transmitted. There are k messages for transmission using the channel j. Let X represents the number of states. Then the probability of switching from channel i to j to transmit further messages is given as:

$$p_{ij} = \begin{cases} \frac{N(k, M-q)}{(M-q)^X}, \ \forall\, i \neq j,\ all\ channel\ available \\ \frac{N(k-r, M-q-r)}{(M-q-r)^X}, \ \forall\, i = j,\ all\ channel\ available \end{cases} \tag{6}$$

Here, $N(k, M-q)$ represents the number of ways k messages are transmitted from the remaining $(M-q)$ messages. For the loop on the same state let r number of messages are already transmitted by the current state, then $N(k-r, M-q-r)$ represents a number of possible ways in which the remaining $(k-r)$ messages are transmitted from $(M-q-r)$ messages.

Algorithm 5 Function for Channel Switching (Markovian Model)

Function `ChannelSwitching(`*Channel*`)`
if *transmitter of* V_a *tuned to CCH && Channel* $==$ SCH_x **then**
  V_a switch from CCH to SCH_x with p_{mn} as eq. (5)
  $assigned\_Channel = SCH_x$
else
  if V_a *tuned to* SCH_k *&& Channel* $== SCH_x$ **then**
    V_a is tuned to SCH_x with p_{ij} as eq. (6)
    $assigned\_Channel = SCH_x$
  else
    if V_a *tuned to* SCH_k *&& Channel* $== SCH_y$ **then**
      V_a is tuned to SCH_y with p_{ij} as eq. (7), (8)
      $assigned\_Channel = SCH_y$
    end
  end
end
return *assigned_Channel*
Function End
Output: Channel is switched to required channel

In case channel 181 is busy then the remaining messages of state S4 are transmitted along with the messages of state S2 and hence the probability of switching from state S4 to S2 is given in eq. (7).

$$p_{ij} = \frac{N(k+l, M-q)}{(M-q)^X}, i=4, j=2, \text{ Channel } 181 \text{ is busy} \quad (7)$$

$$p_{ij} = \begin{cases} \dfrac{N(k+l, M-q)}{(M-q)^X}, i=3, j=5, \text{ Channel } 175 \text{ is busy} \\ \dfrac{N(l+k, M-q)}{(M-q)^X}, i=5, j=3, \text{ Channel } 184 \text{ is busy} \end{cases} \quad (8)$$

Here, k is the messages to be transmitted by state S4 and l is the remaining messages of state S2. If channel 175 or 184 are busy then any of the available channels among these is used for transmission and probability is given as eq. (8). Here, k is the remaining messages to be transmitted by state S5 and l by state S3. In case all the states are busy then the remaining messages wait in the queue with probability 1.

F. COLLISION AND HAND-OVER

Hidden Terminal [85] occurs in case two nodes V_a and V_b are beyond one-hop distance apart and are not aware of the presence of each other. In this case, if V_a and V_b request for the same T_{iSCH_x} then hidden terminal problem can occur. Since in the proposed approach, the T_{iSCH_x} is assigned by the RSU to the vehicle and RSU has all the information of the vehicles registered to it. So, the issue of the hidden terminal is resolved in the proposed approach.

Algorithm 6 Proposed TDMA MAC Approach

Input: V_a,V_b,V_c,C_{RSU} *(For symbols refer system model)*
Function TimeSlotAllocation(M_{SCH_x}) **return** allocated_TS;
Function TimeSlotReuse() **return** TS_reuse;
Function SelectVictimNode() **return** V_v;
Function MessageTransmission(*MSG*) **return** Msg_Status;
Function ChannelSwitching(*Channel*) **return** assigned_Channel;
V_a enters C_{RSU}
if *CCH == idle* **then**
  MessageTransmission(WSA_{V_a})
else
  V_a waits for the CCH to be free
end
V_a send M to V_b
if $T_{iSCH_x} \rightarrow V_a$ **then**
  ChannelSwitching(SCH_x);
  MessageTransmission(M);
else
  if $T_{jSCH_y} \rightarrow V_a$ **then**
    ChannelSwitching(SCH_y);
    MessageTransmission(M);
  else
    TimeSlotAllocation(M_{SCH_x});
    MessageTransmission(WSA_{RSU});
    MessageTransmission(M);
  end
end
Output: Successful transmission of M from V_a to V_b

The following collisions are considered:

1) ACCESS COLLISION [33]

Access collision occurs if the two vehicles try to access the same time slot T_{iSCH_x}. In the proposed approach, RSU has all the information about the allocated time slots. If no time slot is available, then RSU allows the reuse of the time slot T_{jSCH_x} of the vehicle two-hop distance apart. For example, as shown in fig. 5 suppose, there are only three time slots available. Since vehicle V_1 and V_4 do not belong to N_{TH} so V_4 can reuse the same time slot as reserved by V_1.

2) MERGING COLLISION

Merging Collision [86] occurs if two vehicles, V_a and V_b, have reserved the same time slot T_{iSCH_x}. The two conditions for merging collision are: a) the vehicles having T_{iSCH_x}

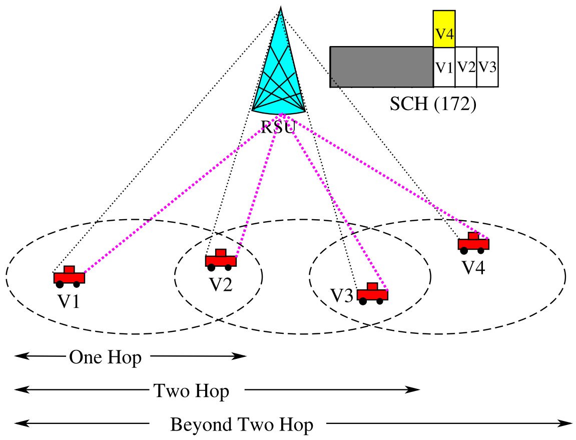

FIGURE 5. Time Slot re-usability to avoid access collision in multi-channel TDMA.

Algorithm 7 Merging Collision in Multi-Channel TDMA MAC

Input: V_a, V_b transmits the WSA_a, WSA_b respectively to the RSU.
V_a and V_b have reserved same T_{iSCH_x} with p_{mn} as eq. (4)
if $V_a, V_b \in D_L \mid\mid V_a, V_b \in D_R$ **then**
  if *$Speed(V_a) > Speed(V_b)$ and V_a is behind V_b* **then**
    RSU selects the victim V_v to release the allocated T_{iSCH_x}
  else
    V_a and V_b continue to use the same T_{iSCH_x}
  end
else
  if *V_a and V_b are moving towards each other* **then**
    RSU selects the victim V_v to release the allocated T_{iSCH_x}
    RSU_2 allocates another time slot T_{kSCH_x} to V_v with p_{mn} as eq. (4)
  else
    V_a and V_b continue to use the same T_{iSCH_x}
  end
end
Output: TS T_{iSCH_x} allocation during Merging collision

moving in a different direction towards each other, b) the vehicles having T_{iSCH_x} moving in the same direction and the vehicle behind has higher speed than vehicle ahead. For V_a and V_b moving towards each other with T_{iSCH_x}, the RSU selects the victim node V_v amongst them using algo. 3. V_v releases T_{iSCH_x} and other vehicle continues to use T_{iSCH_x}. If vehicles are moving in the same direction with T_{iSCH_x}, and come close to each other then RSU selects victim nodes to release T_{iSCH_x}. Merging collision is resolved according to the algorithm. 7.

3) HAND-OVER VEHICLE

When the vehicle V_a registered to RSU_1 moves forward towards RSU_2 stops receiving the messages and services from RSU_1. This condition is known as a handoff. In the case of handoff, T_{iSCH_x} allocated to V_a needs to be rechecked for the availability by the RSU_2. If T_{iSCH_x} is available in the time frame of RSU_2, then V_a continue to use T_{iSCH_x} else the new time slot is allocated to V_a according to algorithm 8.

Algorithm 8 Allocation of TS to the Hand-Over Vehicle

Input: T_{iSCH_x}
V_a moves from range of RSU_1 to RSU_2
RSU_2 receives the WSA_{v_a} consisting of details of allocated T_{iSCH_x}
RSU_2 checks the availability of the T_{iSCH_x}
if *T_{iSCH_x} is reserved by V_b under RSU_2* **then**
  RSU_2 selects the victim node V_v among contending nodes V_a and V_b to release T_{iSCH_x}
  RSU_2 allocates another time slot T_{kSCH_x} to V_v with p_{mn} as eq. (4)
else
  V_a continue to use the same TS T_{iSCH_x}.
end
Output: TS T_{iSCH_x} allocation for hand-over vehicle

V. SIMULATION AND COMPARISON

Simulation of the proposed approach and existing TDMA based multi-channel MAC is done using OMNET++ [87] and Veins [88], and the parameters are shown in table 4. SUMO [89] is used for traffic generation and speed control of vehicles. Vehicles are randomly inserted in chunks via Traffic Control Interface (TraCI). TraCI [90] provides access to the SUMO server using the client-server architecture TCP. The description of the vehicle routes is defined in the file routes.xml in the SUMO. The routes for the vehicles are defined using edges and assigned to vehicles based on vehicle ID. There are five defined routes that are randomly assigned to the chunks of the vehicles. The car-following model is used to maintain the speed of the vehicles. Results of the proposed approach are compared with the existing MAC protocols VeMAC [32], AMAC [21], POCA-C [3], POCA-D [3], Adaptive Multi-channel [11], Adaptive Distributed MAC [14]. The following attributes are compared and analyzed with the above mentioned protocols: a) probability of time slot reservation on required SCH, b) the number of messages transmitted using required SCH, c) Safety and non-safety message transmission using SCH (Type 1, Type 2, Type 3 and Type 4 as shown in table.1 and table. 3), d) an average number of access and merging collision, and e) Throughput. 60 vehicles were considered and the simulation was run for 10 min approximately. Vehicles generate public and private safety and non-safety messages and transmit them to other vehicles and RSU in their network. In the proposed approach V_a sends the message details M_{SCH_x} embedded with WSA_{V_a} to the RSU. M_{SCH_x} gives the details of the t_{SCH_x} required for the message transmission to the RSU that checks for the

TABLE 4. Simulation configuration.

Simulator	Omnet++, Veins	
Traffic Simulator	SUMO (Simulation of Urban MObility)	
Mobility Model	Random Mobility Model	
Map	Open Street Map	
Number of Vehicles	2-60	
Vehicle Speed Range	40-150 km/hr	
Number of SCH	4	
Number of CCH	1	
Message Size	254 bytes	
Message (Type 1,2,3,4) Interval	100 ms	
Message Rate	6 Mbps	
Slot Interval	CCH	20 ms
	SCH 172	16 ms
	SCH 175	16 ms
	SCH 181	36 ms
	SCH 184	12 ms
Number of Slots	CCH	10
	SCH 172	8
	SCH 175	8
	SCH 181	18
	SCH 184	6
Maximum Simulation Time	20000 s	
Simulation Run Time	500 s	
Average Vehicle Speed	60 kmph	

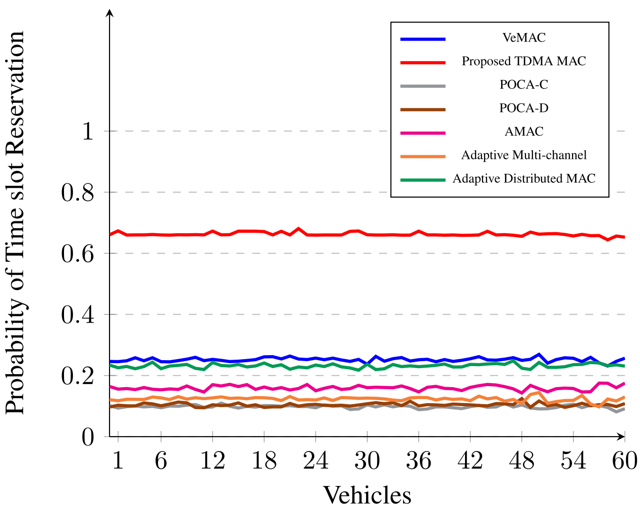

FIGURE 6. Probability of reservation of time slot in the required SCH channel successfully.

availability of the T_{iSCH_x} for allocation to V_a. If T_{iSCH_x} is not available then T_{jSCH_y} is allocated to the V_a. The probability of reservation of the required SCH is approximately 0.7 in the case of the proposed approach. In the existing TDMA based multi-channel MAC protocols the available time slot is allocated from the random SCH channel irrespective of the required SCH channel. Hence the probability of reserving the time slot on the required SCH channel is very low in the existing protocols. Due to random access of the SCH channels in the existing protocols, the probability of reservation of required SCH is approximately 0.2. The variation in the probability as obtained in the simulation is due to the different TDMA approaches. Successful reservation of the time slot in

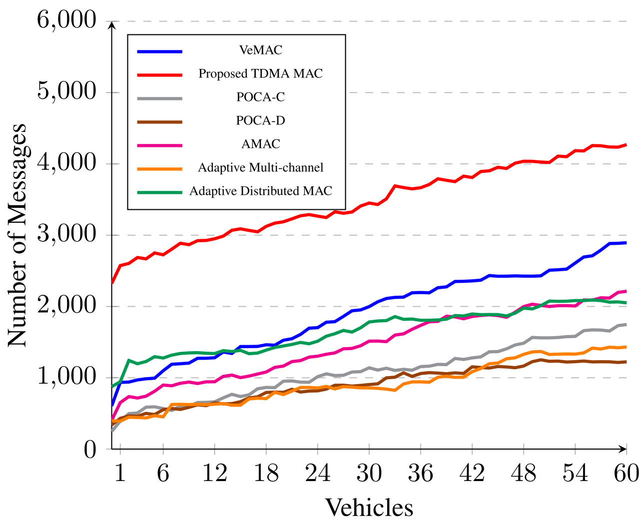

FIGURE 7. Number of messages transmission using required SCH channel.

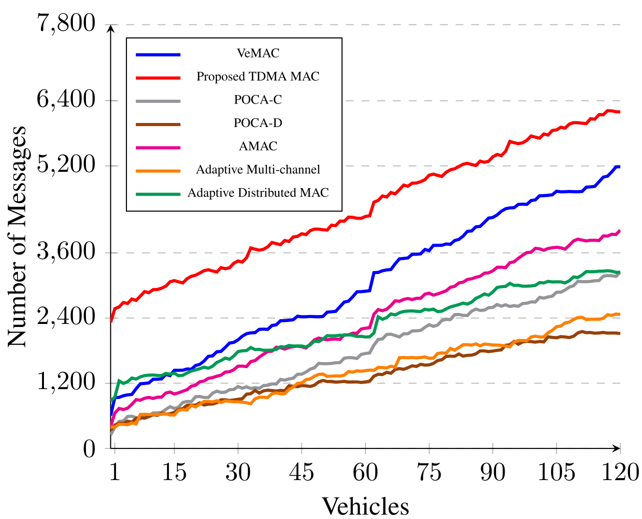

FIGURE 8. Number of messages transmission using required SCH channel for 61-120 Vehicles.

the required SCH allows proper utilization of resources. The probability of successful reservation of the time slot on the required SCH channel is compared in fig. 6.

For initiation of the communication in adaptive distributed MAC during the negotiation period the three-way handshake starts and then the time slot in the available SCH channel is randomly allocated to the vehicles. Based upon the congestion the time slots are allocated to the vehicles on the SCH channel in adaptive multi-channel MAC. In AMAC the channels are selected in a continuous, alternate, or immediate mode based on the congestion of the CCH channel. Instead of focusing on the requirement of the message for transmission the congestion of the CCH channel decides the usage of the channel. In POCA-C primary providers reserve the time slot during CCH and secondary providers reserves the time slot during SCH based on the congestion. In POCA-D Secondary providers stochastically determine the time slot on the SCH

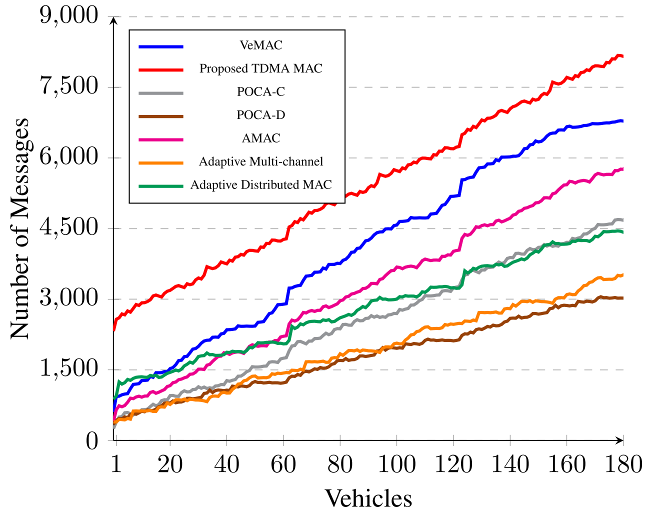

FIGURE 9. Number of messages transmission using required SCH channel for 121 - 180 Vehicles.

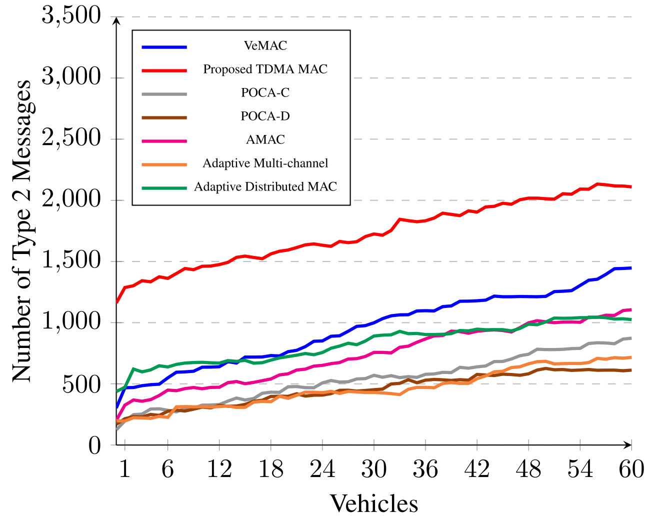

FIGURE 11. Number of Type 2 messages transmitted successfully using the required SCH 181.

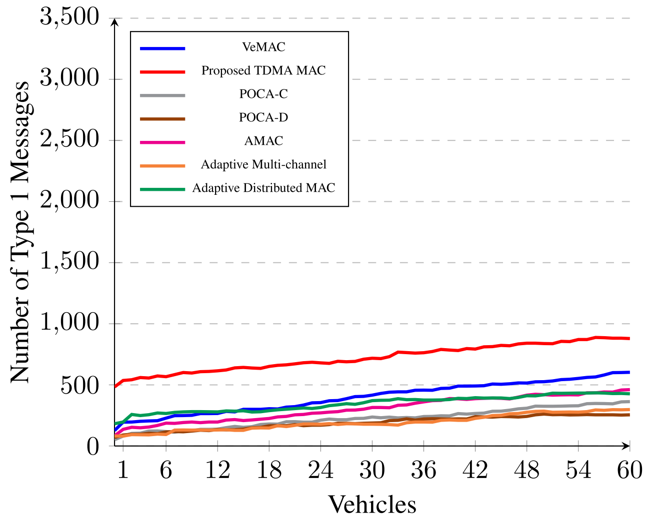

FIGURE 10. Number of Type 1 messages transmitted successfully using the required SCH 175

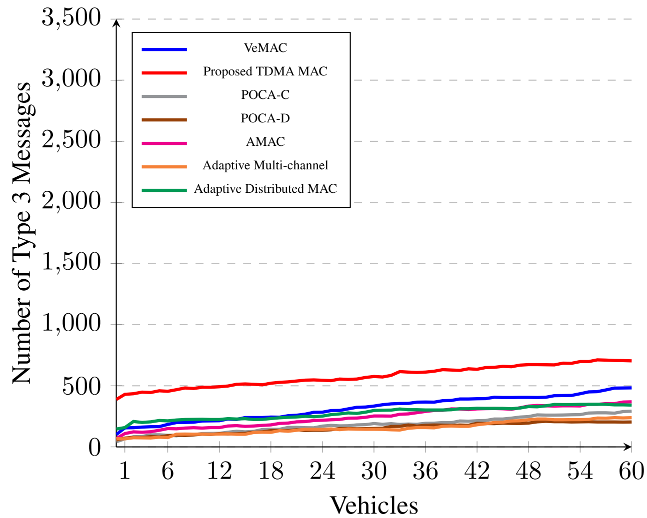

FIGURE 12. Number of Type 3 messages transmitted successfully using the required SCH 172 or 181.

channel for message transmission. In VeMAC the vehicle reserves a time slot on an SCH channel and continues to use it till the transmission collision occurs. These multi-channel protocols focus on the allocation of the SCH for message transmission without checking the channel requirements for the message transmission. The proposed approach checks for the requirements of the message to be transmitted. Messages are categorized as Type 1, Type 2, Type 3, and Type 4 based on the required channel properties. Fig. 7 shows the number of messages that are transmitted using the required SCH for optimized resource usage. From the graphs, it is visible that the Proposed TDMA Multi-channel MAC protocol provides the correct usage of the required channel as compared to other protocols.

A. SCALABILITY

To test the scalability of the proposed approach we have increased the number of vehicles from 60 to 120 and further to 180. We have compared the results obtained for the number of messages transmitted using the required SCH for 60, 120, and 180 vehicles as shown in fig. 7, 8 and 9 respectively. The approximate percentage of messages transmitted for 60, 120 and 180 vehicles for VeMAC is 61%, for adaptive distributed MAC is 47%, for adaptive distributed MAC is 41%, for POCA-C is 38%, for adaptive multi-channel MAC is 34%, for POCA-D is 27% and for the proposed approach is 89%.

Fig. 10 represents the number of messages transmitted successfully using the required SCH 175 for Type 1. The successful transmission of the Type 2 messages using the

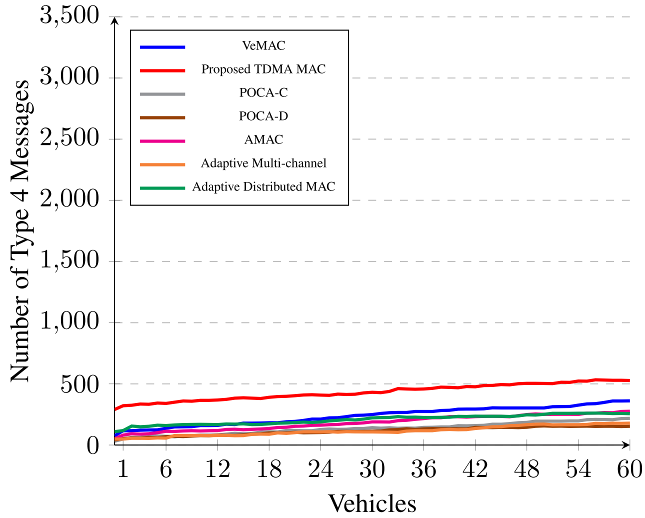

FIGURE 13. Number of Type 4 messages transmitted successfully using the required SCH 175 or 184.

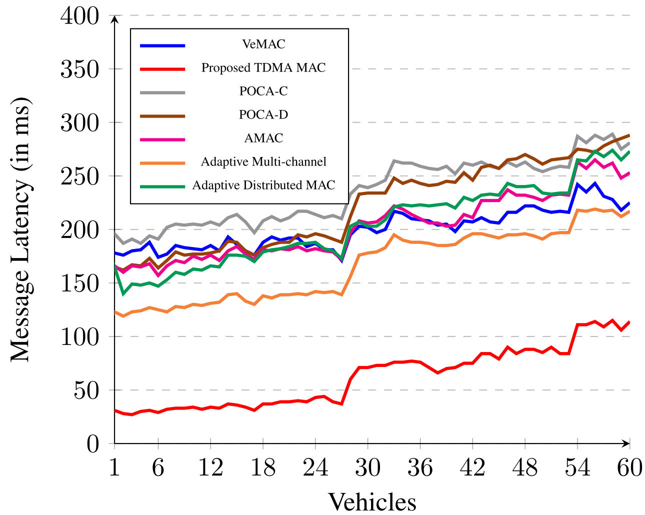

FIGURE 14. Message Latency for Type 1 Messages on SCH 175.

required SCH 181 is represented in fig. 11. Fig. 12 represents the comparison of the successful transmission of Type 3 messages using required SCH 172 or 181 by various protocols. Comparison of the protocols for sending the Type 4 messages using required SCH 175 or 184 is represented in fig. 13. It is observed that the proposed approach transmits the maximum number of messages, of each type, using the required SCH. Other protocols transmit less number of messages using the required SCH. This is because in the proposed approach the request to reserve the required SCH for the message transmission is sent to the RSU along with the WSA. In other protocols, SCH channels are randomly allocated based on their availability without concern about the required SCH channel. Simulation results indicate that for the proposed approach optimized resource utilization is achieved by reserving the time slots in the required SCH.

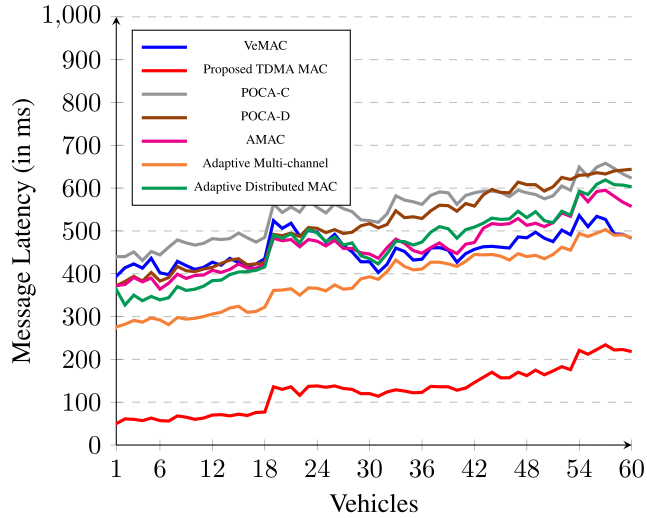

FIGURE 15. Message Latency for Type 2 Messages on SCH 181.

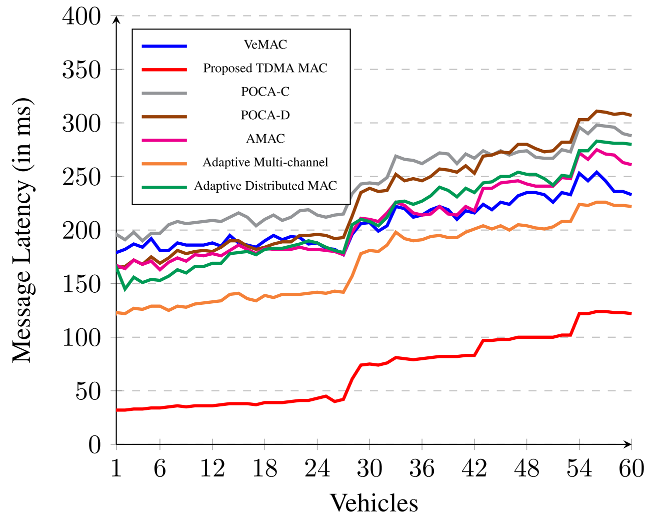

FIGURE 16. Message Latency for Type 3 Messages on SCH 172 or 181.

Message latency is the time taken to transmit the message from source to destination. In POCA-C the time slot is allocated to the primary providers and later to the secondary providers. Hence the waiting time of the secondary providers contributes to the latency of the message transmission. In POCA-D time slots are allocated stochastically to the secondary provider on the SCH. Channel is allocated to the vehicles based on the load of SCH in adaptive multi-channel MAC, and load of CCH in AMAC. VeMAC continues to use the allocated time slot over the SCH irrespective of message requirements. Adaptive distributed MAC allocates time slots randomly of the available SCH channel. So the allocation of time slot for the random SCH over utilizes the resources leading to increased waiting time for some of the vehicles affecting the message latency. Due to allocation of time slot in required SCH the message latency is less in the proposed approach as compared to the other approaches. Message

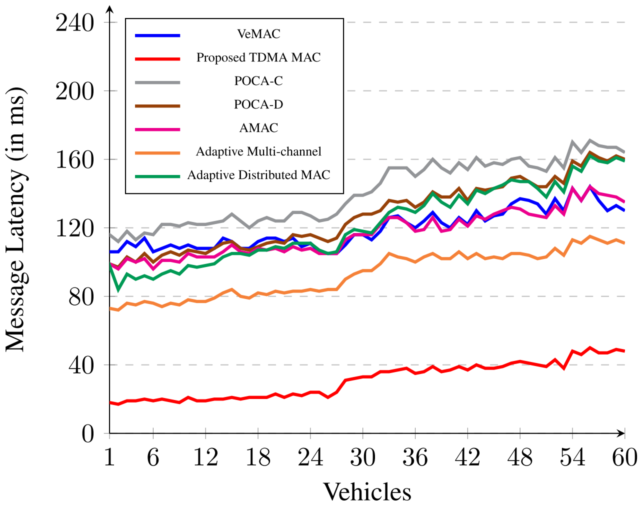

FIGURE 17. **Message Latency for Type 4 Messages on SCH 175 or 184.**

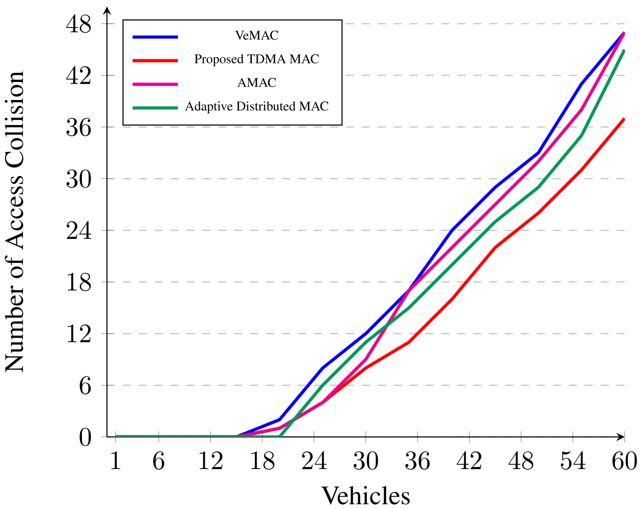

FIGURE 18. **Average Number of Access Collision.**

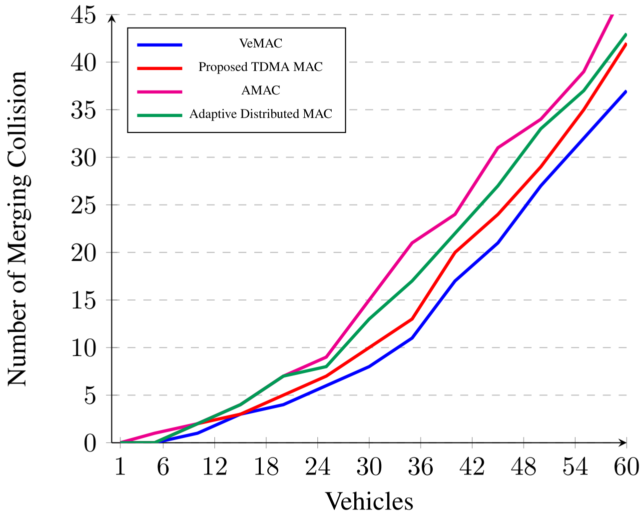

FIGURE 19. **Average Number of Merging Collision.**

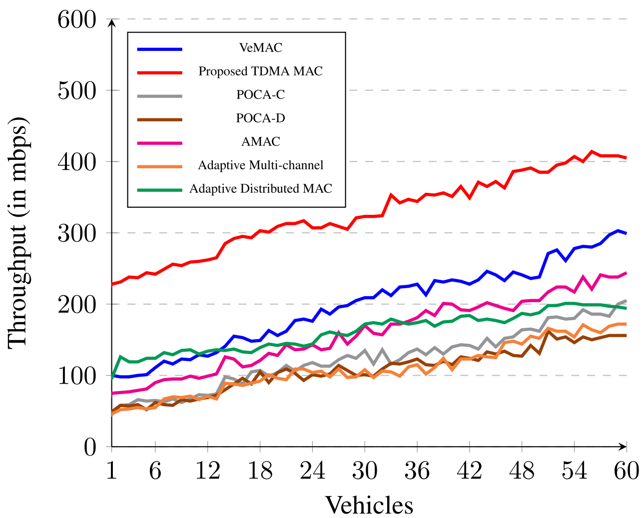

FIGURE 20. **Throughput Comparison in Multi-channel TDMA MAC.**

latency for Type 1 messages is shown in fig. 14, for Type 2 messages is shown in fig. 15, for Type 3 is shown in fig. 16, and for Type 4 is shown in fig. 17.

Access collision occurs if multiple vehicles access the same time slot. In VeMAC, AMAC and adaptive distributed MAC the time slots are allocated on the random SCH based on availability. In the proposed approach, the time slot for different SCH channels is allocated based on the number of messages for transmissions and the reuse of time slots after two hops. This reduces the number of access collisions as compared to other approaches. The comparison of access collision for different approaches is shown in fig. 18.

A merging collision occurs if two vehicles with the same time slot reservation are approaching each other. The number of merging collisions is least in VeMAC as it uses a disjoint set of time slots for vehicles moving in a different direction. In AMAC and adaptive distributed MAC, the reserved time slots are used for the full transmission till a merging collision occurs. In the proposed approach, the time slots are freed after the completion of messages transmission and hence the number of merging collisions is less. Merging collision for different approaches is compared in fig. 19.

The number of messages transmitted between the source and destination vehicles is calculated as throughput. In adaptive multi-channel, POCA-C, and AMAC the criteria for channel allocation is traffic density. In POCA-D, primary providers wait for the allocation of channel resources. If allocated channel resources are less than required then random resource allocation in adaptive distributed MAC leads to message loss. In VeMAC, the continuous use of allocated channel resources increases waiting time for vehicles which leads to low throughput. In the proposed approach, the appropriate allocation of channel resources leads to minimum message loss contributing to high throughput. The throughput for different approaches is shown in fig. 20.

VI. CONCLUSION

Communication among the vehicles requires timely delivery of public and private safety and non-safety messages. The SCH channel required for the transmission may be acquired by multiple vehicles leading to a collision. TDMA approach provides a dedicated time slot for accessing channels without collision. Existing MAC approaches allocate an available time slot on the random SCH channel. However, based on the requirements of the message the specific SCH channel must be used for transmission. Allocating time slot on a random SCH channel leads to over-utilization or under-utilization of channel resources. In the proposed approach messages are categorized into four types based on the SCH channel requirements. Variable-sized time frames are used for SCH based on the message density of each type. The information of the required channel for message transmission is sent to the RSU. The required SCH channel is checked for the availability of the time slot. The available time slot is assigned to requesting vehicles for optimized resource usage. In the proposed approach, the probability of reservation of time slot for the required SCH is approximately 0.6 using the Markovian model whereas for other protocols it is approximately 0.2. The message transmission rate and throughput for the proposed approach are improved over other approaches. The proposed approach guarantees timely delivery of messages and has reduced message latency. Access collision and merging collision are also considered in the proposed approach. The proposed approach focuses on the timely and guaranteed delivery of safety, non-safety, public and private messages as shown in table 1 and table 3. The limitation of the proposed approach is the consideration of Infotainment messages. As a future scope, we will consider the security challenges for multi-channel TDMA MAC for required SCH.

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