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# Validating New and Existing MAC Algorithms for VANET

*Master of Science Thesis in Networks and Distributed Systems*

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Göteborg, Sweden, October 2009

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# Abstract

A vehicular ad-hoc network (VANET) is an autonomous and self-configuring network of mobile hosts connected by wireless links. Most of the existing Medium Access Control (MAC) algorithms that are used in VANETs are designed for stationary settings. In non-stationary setting when mobility is introduced, the nodes that are sensing the channel are not stable and changing rapidly. These rapid changes cause to collisions and packet drops in the channel which decreases the throughput of the network. This project investigates a modification for the existing MAC algorithms for vehicular ad hoc networks. P-persistent CSMA and distributed TDMA slot assignment algorithm are tested in this project.

The modified algorithm divides the radio time into periods. Nodes that are traveling in opposite directions use different time periods. By this method the channel conditions do not change rapidly. The goal of the project is to validate that the modified algorithm indeed improves the throughput. We also studied the performances of our designs and implementations in a network simulator. The results show that the modification mentality used in this project is working but not for all algorithms.



**Keywords:** Vehicular ad-hoc networks (VANETs), Medium Access Control (MAC), P-persistent CSMA, distributed TDMA slot assignment algorithm

## Acknowledgements

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# 1. INTRODUCTION

## 1.1. Project Motivation

A vehicular ad-hoc network (VANET) is an autonomous and self-configuring network of mobile hosts connected by wireless links. In VANET, hosts are free to move on predefined paths (the network of roads) and communicate among themselves within a limited area. Vehicular networks such as [9] do consider base stations, but in this project they are using MANETS' infrastructure where each node is the destination of some information packets while at the same time it can function as relay station for other packets to their final destination. This infrastructure can greatly improve the Vehicular Networks' performances [1].

In most of the medium access control (MAC) algorithms the relocation of mobile nodes did not considered. Alternatively, when it is assumed that the nodes are not stationary, designers tend to assume that some nodes temporarily do not change their location and coordinate the communications among mobile nodes [2]. In this project it is studied to design and implement a modification for the existing MAC algorithms when all the nodes are mobile. The aim of this modification is to decrease the packet collisions in order to increase the throughput of the network.

## 1.2. Objective

The main goal of vehicular networks is providing safety and comfort for passengers. Using vehicular networks, drivers could be alerted on road hazards, crashed cars and road conditions which make the driver to choose the best way along the path. These reasons make the necessity of the modification for non stationary settings essential.

Throughput feature of the modified MAC algorithm is investigated for a finite number of transmitters and receivers. Throughput is the average fraction of time that the channel is used for useful data communication. (The reasons for the throughput degradation are propagation delay, user's idle [not transmitting] period, and packet collision [overlapping of transmissions from multiple users.]) [3]. Java in Simulation Time / Scalable Wireless Ad hoc Network Simulator (JIST/SWANS) is used as a traffic and network simulator to simulate the real life traffic.

To increase the throughput of the network, existing MAC algorithms should be modified for non stationary settings. In the existing MAC protocols when mobility is introduced, the nodes that are sensing the channel are not stable and changing rapidly. These rapid changes during the packet transmission cause to collisions and packet drops in the channel which decreases the throughput of the network. In the modified version of the MAC algorithms that we proposed, time is divided into odd and even periods. A node uses the same time period with the nodes that are traveling in the same direction and different time period with the nodes that are traveling in the opposite direction. By this method the nodes do not enter to the same neighborhood suddenly during their transmission. This provides the channel conditions do not change rapidly. To achieve the fairness requirement of the algorithm, an unbalanced time division can be also done according to the ratio of the cars traveling in the reverse directions.

As a result of this project we want to validate that the algorithm of Papatriantafilou and Schiller improves the throughput of the network in non-stationary settings.

### 1.3. Outline of the content

Section 2 describes the modification technique used in this project for p-persistent CSMA and distributed TDMA slot assignment algorithm. In Section 3, implementations of the modified version of algorithms are described. This is followed in Section 4 by a description of the experiments conducted in this work. Simulation results are presented and discussed in Section 5. Section 6 mentions a future work. Finally conclusions are presented in Section 7.

# 2. PROJECT DESCRIPTION

Existing MAC algorithms are implemented for the networks where all the nodes are stationary. But there might be a problem when the mobility is introduced. Because of this it is required to do some experiments with the existing MAC algorithms in stationary and in non-stationary settings. At the end of the experiments if it is showed that there is throughput degradation in non-stationary settings of the vehicles when compared with the stationary settings. Then one may wish to consider a modification for the existing MAC algorithms for VANETs in non-stationary settings. One way is a Reservation Base MAC algorithm. There might be a significant improvement in the throughput results after this modification compared to the original MAC algorithms which are designed for the stationary settings. We are going to investigate two different MAC algorithms as p-persistent CSMA and Distributed TDMA slot assignment algorithm [4] in stationary and in non-stationary settings. If a serious problem is observed in non-stationary settings then, modifications will be implemented for these algorithms as explained in the below sections.

## 2.1. Modification of p-persistent CSMA

One method for channel access protocols for packet communication systems is the random access technique, where there is only a single channel exist and all the nodes try to access this channel in a contention manner to use the bandwidth of the channel for packet transmission [3]. Carrier sense multiple access (CSMA) is included in this category. Carrier Sense Multiple Access (CSMA) is a medium access control (MAC) protocol being widely used in many popular networks such as 802.3 Ethernet and 802.11 Wireless LAN (WLAN) [5]. We tried to improve the P-persistent CSMA as a first option because it is one of the most common channel access algorithm.

The working principle of P-persistent CSMA is:

- Step 1: If the medium is idle, transmit with probability p, or wait for a propagation delay of one packet with probability (1-p)
- Step 2: If the medium is busy, continue to listen until medium becomes idle, then go to Step 1
- Step 3: If transmission is delayed, continue with Step 1

Each node can send a message to every other node within a distance ≤ R. This distance is determined by the range of the radio signal. $N_p$ is called the neighborhood of node p. The messages sent by node p are broadcasted to the nodes in $N_p$. But the delivery of these messages to the nodes in $N_p$ is not guaranteed. There may be packet collisions because of the concurrent broadcasting of other nearby nodes. $N_p^2$ is the second neighborhood of the node p [4]. Because of the hidden node problem in ad-hoc networks we are going to consider the second neighborhood in this project also.

Existing MAC algorithms such as p-persistent CSMA, share a strategy for avoiding collisions. In this strategy nodes sense the channel, if channel is idle the node either transmits with a probability p or back-off for one packet transmission time with probability q=1 – p. If the channel is sensed idle again then it either transmits or defers with probabilities p or q. But if the channel is sensed busy, it continues to sense the channel until it becomes idle and then continue from the idle condition. This strategy is a good tradeoff between non-persistent and 1-persistent CSMA. The nodes insist on sending the message by continuously sensing the channel which decreases the longer delays and they also use a back-off strategy which decreases the probability of collision. But they can not use this strategy with the other nodes that are not in their neighborhood. So, if two nodes that can not sense each other enter to the same neighborhood during their transmission, there will be collisions. Since the MAC algorithms are fault tolerant, the nodes may tolerate these faults if the nodes are not fast, but if they are fast, there will be collisions and packet drops in the channel which decreases the throughput of the network. Because of this reason we want to improve the existing MAC algorithm for non-stationary settings. In the existing MAC algorithm all nodes that are sensing the same channel, try to capture the channel and start transmission. Any node can capture the channel, either the node moving in the clockwise direction or in counter-clockwise direction. But in the modified version of the MAC algorithm, total radio time is divided into communication cycles and every communication cycle is divided into communication periods as can be seen in Figure 1.

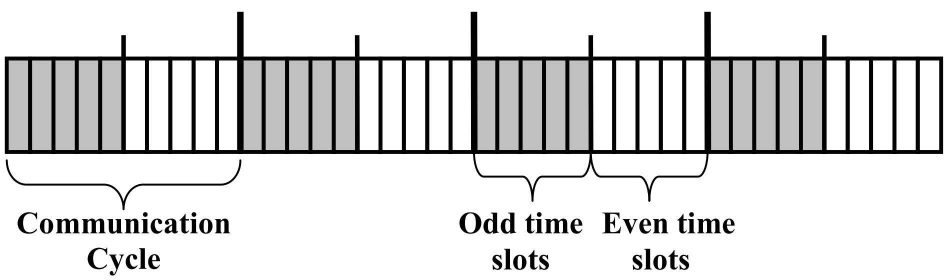


**Figure 1** Sample radio time of the modified MAC algorithm

If the even time periods are used by the nodes that are traveling in the clockwise direction then the odd time periods will be used by the nodes that are traveling in the counter-clockwise direction. Since the cars traveling in the opposite directions use different time periods, it is guaranteed that, there will not be any two nodes that use the same time period for transmission enters the same neighborhood suddenly during their transmission time. This provides less packet collisions in theory. An unbalanced time division can be also done according to the ratio of the cars traveling in opposite directions. Suppose that the vehicles are placed uniformly on the road and they are following one of the directions as α and β, which are opposite to each other. By the uniform distribution we mean that in every part of the road $\chi_\alpha$ % of the cars are going in direction α and $\chi_\beta$ % of the cars are going in direction β, where $\chi_\alpha$ and $\chi_\beta$ are known. We also assume that no car changes its relative location to the other cars in its flows. So, the algorithm can allocate χα % of the bandwidth to the cars traveling in α direction and $\chi_\beta$ % to the ones traveling in β direction. For example, cars can share the communication periods as: $[0, \chi_\alpha)$ and $[1- \chi_\beta, 1)$ where the interval [0, 1) represents one communication cycle [2]. Then the total radio time can be seen like in Figure 2.

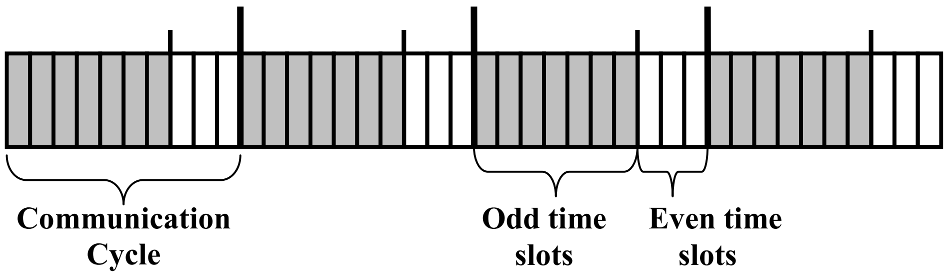


**Figure 2** Sample radio time of the modified MAC algorithm in an unbalanced manner

## 2.2. Modification of distributed TDMA slot assignment algorithm

We try to improve the distributed slot assignment algorithm secondly because it is a slot based communication protocol, where the communication time is divided into small communication slots, which is different from the P-persistent CSMA algorithm. And also we think that it will be easier to see the effect of mobility in this algorithm.

The main purpose of this algorithm is assignment of TDMA slots to different nodes distributively. To achieve this purpose the algorithm firstly must ensure that no two nodes within distance two have the same color. (The reason of distance two neighborhood is again because of the hidden node problem.) The slot allocation will be according to the colors of the nodes and to get more bandwidth it is important to have small number of different colors in distance two neighborhood. Naturally, if a node p sees a $k<\lambda$ different colors in its distance two neighborhood, then it should have at least $1/(1+k)$ share of the bandwidth, which is more efficient than having a $1/(1+\lambda)$ share from the bandwidth. Consider the two colorings shown in Figure 3, which are the different colorings of the same network [4].


**Figure 3** Two different solutions to distance two coloring a) first coloring b) second coloring [4]

According to these coloring techniques the size of the different colors for each node p can be seen from Figure 4.

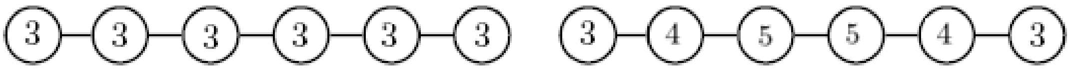


**Figure 4** Number of different colors used in distance two coloring a) According to first coloring in Figure 3 b) According to second coloring in Figure 3 [4]

As can be seen from Figure 4, the first coloring technique is better than the second one in terms of using the channel bandwidth more efficiently. To have a collision free model it is sufficient to assign colors to each node and use these colors as the schedule for a TDMA approach [4]. For this purpose algorithm partitions the radio time into two parts as: TDMA and Overhead. Overhead part is reserved for the messages that assign colors and time slots to nodes and the TDMA is used for the application messages. CSMA/CA is used to manage the collisions in overhead section but there is not any collision avoidance technique used in the TDMA slots except the carrier sensing technique [4].

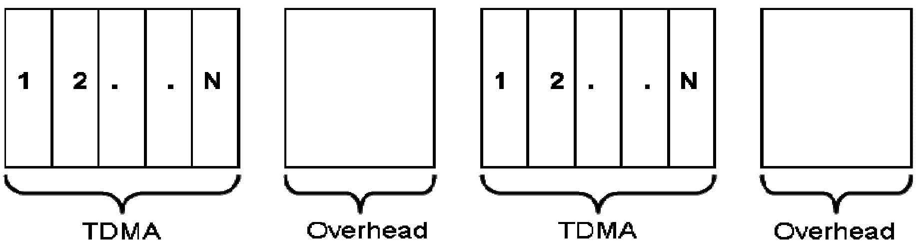


**Figure 5** Sample schedule for Distributed TDMA Slot Assignment Algorithm [4]

The base number of a node defined as the number of different colors in distance two neighborhood of the node. According to this definition, the rightmost node p in the second coloring of Figure 3 has a base number 3 and the node q which is the neighbor of node p has a base number 4 which means that node p must use at least 1/3 of the TDMA slots and node q must use at least 1/4 of the TDMA slots [4].

This algorithm claims that the system is collision free after the stabilization of any transient fault or topology change event. Since we want to use this algorithm in a highly dynamic environment we believe that the throughput of this algorithm will decrease significantly in non-stationary setting compared to stationary setting. Because of this reason, we want to improve this algorithm for highly dynamic environments.

In the improved version of this algorithm, before the communication period there will be a meeting period for the nodes to identify its permanent neighbors. The nodes will store a neighbor table where they are going to store the message records of the neighbor nodes. These records include the unique identifier property of the nodes and the time property when the message has received. Since all node clocks are synchronized to a common global time, there will not be any disorder in the time field of the records. In meeting period and in overhead sections every node will repeatedly broadcasts an "I am alive" message to all of its neighbors and when a node receives the "I am alive" message, it updates its neighbor table. If the sender node's id is not in the neighbor table then it is added to the table and if it is already in the table then the time property is updated according to the time that the message received. The record will be removed from the neighbor table if it is not refreshed by the arrival of a new message for a period longer than Є. Eventually the set of neighbors will be the processors' identifiers of the message records that were stored in the table for a period longer than Є [2]. So the permanent neighbors of a node will be the nodes that they are traveling in the same direction. It is also assumed that if node A is in the neighbor table of node B then, the node B must be in the neighbor table of node A also [4]. If we again suppose that the vehicles are placed uniformly on the road and they are following one of the directions as α and β, which are opposite to each other and if we also assume that no car changes its relative location to the other cars in its flows. So, the algorithm can allocate $\chi\alpha$ % of the TDMA slots to the cars traveling in α direction and $\chi_\beta$ % to the ones traveling in β direction. TDMA slots can be shared as: $[0, \chi_\alpha)$ and $[\chi_\alpha, 1)$ where the interval $[0, 1)$ represents one TDMA section. Then the schedule for the nodes will be seen like in Figure 6.

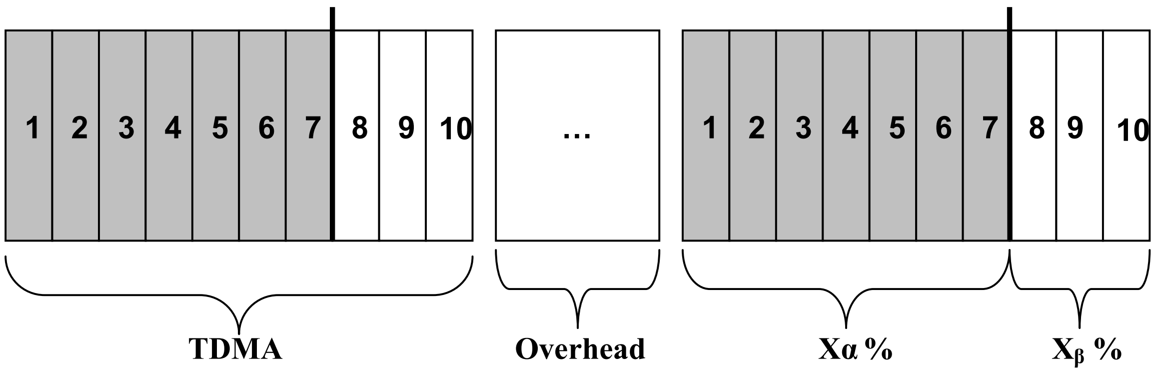


**Figure 6** Sample schedule for the improved version of Distributed TDMA Slot Assignment Algorithm

Since the vehicles traveling in different directions use the different slots of the TDMA part, it is guaranteed that; there will not be any two nodes with same color enter the same neighborhood suddenly during their transmission time which decrease the collision probability and increase the throughput of the network.

# 3. IMPLEMENTATION

There is an increasing interest in developing the network protocols and services for VANETs. Because of the excessive amount of expenses and efforts of deployment and implementation of these systems in real world, most of the research in this area relies on the simulation for the evaluation of the systems. In our simulations we have used Jist/Swans (Java in Simulation Time / Scalable Wireless Ad hoc Network Simulator). For the traffic simulations we deal with the macro level traffic simulator which means that; we don't deal with the local behaviors of the vehicles, we just deal with the observable behaviors of the vehicles such as, the volume of the cars in one part of the road and/or the average speed of the cars. For the simulations we have used a square 2D path and we have used 200 cars that all of them have a unique identifier. For the communication, the vehicles use local broadcasting where they can send their messages within a limited distance but the delivery of these messages are not guaranteed. The vehicles are placed randomly on a square path and we assume that no vehicle change its relative location according to the other vehicles.

In the remaining part of this section we are going to explain the implementation of the improvement of two different MAC algorithms.

## 3.1. Implementation of modified p-persistent CSMA algorithm

All nodes randomly and uniformly distributed along the rectangular map. In the initial part of the simulation all nodes choose a direction to follow during the simulation time without changing it. In our simulation 33% of the nodes travel in clockwise direction and 67% of them travel in counter-clockwise direction. We have divided the total radio time into communication cycles according to the packet transmission time and number of nodes. In every communication cycle, clockwise traveling cars use either the first or the last 33% of the cycle and counterclockwise traveling cars use the remaining %67 of the communication cycle. The created packets are stored in the packet queue and when a node wants to broadcast a message, it first checks if the radio time is in the appropriate communication period for its traveling direction. If it is not in the appropriate communication period, then node back off until the next packet creation. But if the radio time is in the appropriate communication period then it starts to sense the channel until it finds the channel idle, then it either transmit with probability p or delay the transmission with probability (1-p). If the message is sent then it is deleted from the packet queue.

## 3.2. Implementation of modified distributed TDMA slot assignment algorithm

In this algorithm again 33% of the nodes travel in clockwise direction and 67% of them travel in counter-clockwise direction. After the placement of the vehicles on the square map randomly, the stabilization period (meeting period) starts where all the nodes broadcast "I am alive" messages to all of its neighbors repeatedly. The stabilization period is long enough for all the nodes to identify their permanent neighbors. After the stabilization period, the communication period will start which includes the TDMA and the overhead sections. The number of slots in the TDMA section, the length of the slots and the length of the overhead section can be adjusted according to the total number of nodes in the simulation and the packet transmission time. In the stabilization period we set the colors and the transmission slots of the nodes and if there will be any change in the topology of the network, then the nodes will adapt to these changes in the communication period.

The other difference from the original algorithm is the coloring algorithm. In the original algorithm for assigning the colors to the nodes, first all nodes choose a leader node that will assign the colors to itself and to other nodes in its domination area. Every node chooses its own leader according to the minimum id number of the nodes in its neighbor table. Therefore there will not be any global leader for all the nodes but there will be local leaders. But in the improved version of this algorithm we will not choose any leader node, the nodes will set their color according to the shared information distributively in the stabilization period. The colors will be set according to the total number of nodes in the neighbor table and the id information. The nodes that have the maximum number of nodes in its neighbor table will get the minimum color. If there are the two nodes that are in the same neighborhood and have same number of neighbors in their neighbor table then the node that has a smaller id will get the smaller color. The nodes will set their color not only looking to their own neighbor table but also to the neighbor node's neighbor table. According to this distance two coloring the color information of the nodes will be local which means that there will be more than one same color but these nodes can not be in the neighbor table of each other.

After the assignment of distance two coloring, the next task is to assign time slots of the TDMA section for each node. Nodes will use the assigned period of the TDMA slots for its direction. Every node will get a share of the bandwidth according to the number of different colors in its neighbor table (base number). According to this rule each node in the same neighbor table may get a different share of the bandwidth. But this does not violate the fairness if these slots would otherwise be wasted [4]. The slots are captured starting from the first slot of the period that is assigned for the nodes' direction. First slot is captured by the node that has a maximum color in its neighbor table because most probably the maximum color node has a base number smaller than the other nodes which make this node needs more transmission slots to be used. Then the other nodes capture the first available slot by checking the transmission slots of the node in its own neighbor table that has one color more than itself. Since the maximum color information is also local information, it may be different in all the neighbor tables. After every node set its transmission slots, if there are some slots that have not captured already these slots will be captured at the end also by the nodes that need these slots.

At the end of the stabilization period the transmission slots are sorted in an increasing order. In the TDMA sections the application packets are created and stored in the application packet queue. When the nodes try to send these application messages, firstly it is controlled if the time slot is the correct time slot for the node. If not, the node scheduled for its correct transmission slot. But if it is the correct time slot then the node sense the channel until it finds it idle. Since the channel is reserved for that node at that time slot, it will not be hard to find the channel idle, and then the node will send its application message. After sending the message successfully this message will be removed from the application packet queue and the node will be scheduled for its next transmission slot. By the successful implementation of this algorithm the probability of collision is decreased significantly and the delivery of the messages to most of the neighbors are provided.

# 4. EXPERIMENTS

In our project we dealt with two different MAC algorithms. To understand the effect of our modification we examined both of the algorithms with the same experiments. We are mainly interested in the throughput of the messages and which to understand the relationship between stationary settings and non-stationary ones. In wireless communications, a single broadcast can be received by several recipients. We consider an arbitrary recipient and the number of received messages as a result of a single packet transmission.

The throughput is the average fraction of time that the channel is used for useful data communication. We can simplify our analysis by considering the number of received messages as a result of a single packet transmission [3]. Suppose we let all the nodes to store the messages that they receive. If we assume that there are n nodes and every one of them sends m messages, then the required memory space is in O(nm). We wish to reduce the memory requirements. Therefore, we chose to store messages from only 10% of the nodes. We define that these nodes have the id numbers of 10, 20, 30…, 190, 200 and we call these nodes the *sample nodes*. We used two files for storing information about the sample nodes. The messages that the sample nodes sent are stored by these nodes in a text file (Send.txt). All the mobile nodes store the messages that are received from the sample nodes (Receive.txt). These text files are used for calculating the statistics; we import these files to a database and match between records of the sent and received messages.

For both stationary and non-stationary settings, p-persistent algorithm is considered for four different values of p: 1, 0.75, 0.5 and 0.25. We also consider different traffic loads in order to discover the relationship between the throughput and traffic load, i.e., we take into account different delays between packet creations (cf. Table 1). To calculate the average traffic load first it is needed to calculate the expected number of nodes in $N_p$. The average traffic load result can be obtained by multiplying the expected number of neighbors with the transmission attempts of one node per frame time. The calculation of the expected number of neighbors is in the Appendix A. We repeat each experiment four times and calculate the average values. At the end of the experiments, stationary and non-stationary settings are compared.

The results of the experiments are analyzed in two parts. In the first part of the experiments, existing MAC algorithm are tested in stationary and in non-stationary settings. At the end of this part it is required to show that there is degradation in the average number of received messages in non-stationary settings when compared with the stationary settings. Then we can prove that there is a problem with the existing algorithm for VANETs when the nodes are mobile so we can pass to the second part of the experiments. In the second part of the experiments, modified version of the existing MAC algorithm is tested in non-stationary settings. In this part, to prove that our algorithm is working better than the existing MAC algorithm in non-stationary settings we need to show that; there is an observable increase in the average number of received messages for modified version of the algorithm when compared to original version.

## 4.1. Experiment Setup

We now turn to explain the setup of the experiments. The road is a circular path in the form of two dimensional square of 5km by 5km. There are 200 (mobile) nodes. The nodes are placed on the road uniformly at random. Every node has a unique id. We assume that at any node there is a bounded delay between two consecutive creations of data packets from the application layer (cf. Table 1). The messages that we consider are of the form<sender id, message id>, where sender id is the id number of the sending node and message id is an enumerated number of the message (i.e., we ignore the actual data field). We consider two types of experiment: one of stationary settings and one of non-stationary settings.

**Table 1** The delay between two packet creations

| Delay id | Delay |
|---|---|
| 1 | 40ms |
| 2 | 20ms |
| 3 | 6.5ms |
| 4 | 3.2ms |
| 5 | 1.6ms |
| 6 | 1.0ms |

In the non-stationary settings, each car is traveling either in the clockwise direction or in the counter-clockwise direction. We assume that there is a known ratio between the cars that travel in these directions. All the vehicles move with same speed in the direction that is assigned in the beginning of the simulation and again they communicate with each other by application messages. Moreover, all vehicles move at the same speed in the same direction that was initially assigned.

An example for the experiment setup is given in Figure 7. There are 15 vehicles in total 5 of them are red and move in clockwise direction and 10 of them are blue move in counter-clockwise direction. The ratio between the directions is 1/3.

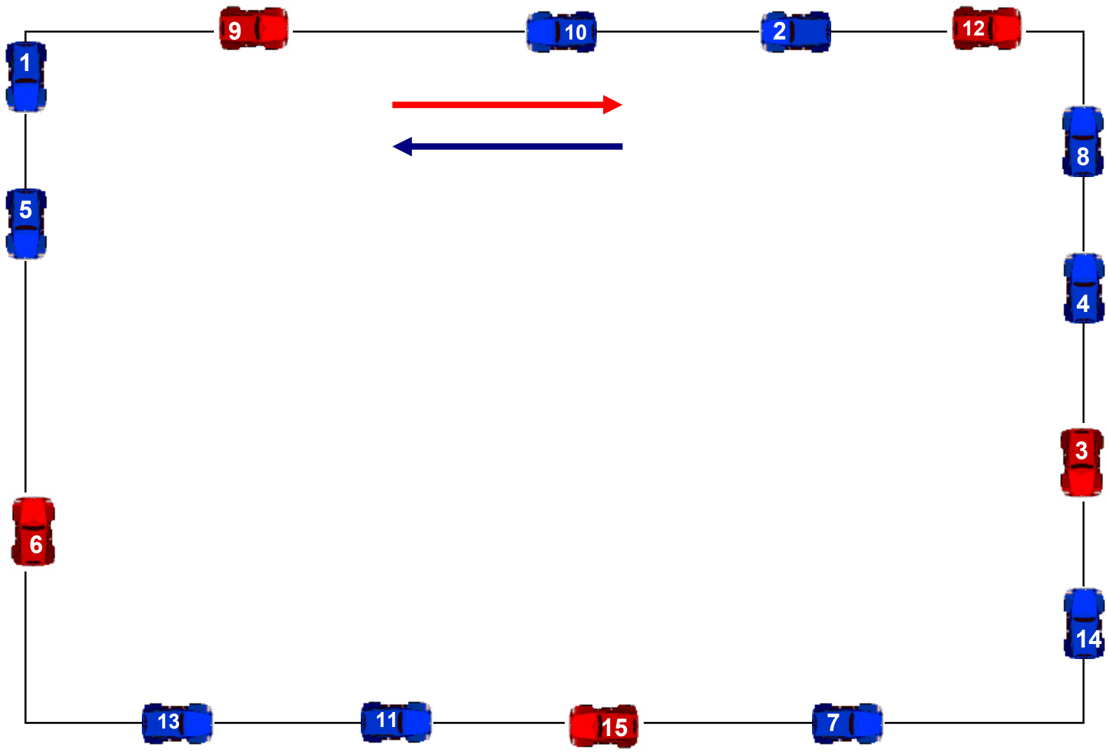


**Figure 7** Sample configuration of an experiment setup

In the modified version of the algorithm 33% of the vehicles travel in the clockwise direction and 67% of them travel in counter-clockwise direction throughout the simulation. For the communication of the nodes between each other, nodes use local broadcasting where they send their message to every node within distance ≤ R. The deliveries of these messages are not guaranteed and there is not any acknowledgment mechanism.

# 5. RESULTS

In this section, it is started with analyzing the results of the original P-persistent CSMA algorithm. In Figure 8, the number of received messages in one packet transmission time with respect to increasing average traffic load is seen for 1-persistent CSMA in stationary and in non-stationary settings.

In stationary setting, with increasing packet send rate of the nodes number of received messages is increasing also. But after some point the network is saturated and the number of received messages is decreasing with the increasing average traffic load. In non-stationary setting, the network is saturated earlier than the stationary setting.

In all conditions of the average traffic load, it can be easily seen that the number of received messages in non-stationary setting is drastically decreased when compared with the stationary settings. This result proves the hypothesis, saying that the existing MAC algorithms are implemented for the networks where all the nodes are stationary. But there might be a problem when the mobility is introduced.

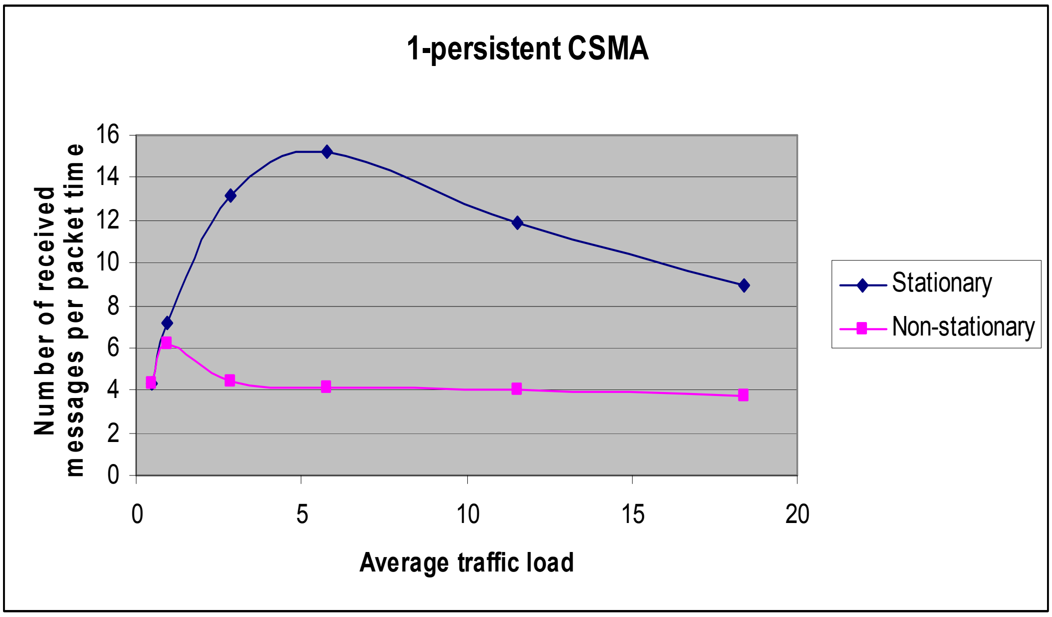


**Figure 8** Number of received messages per packet time versus average traffic load in stationary and in non-stationary settings for 1-persistent CSMA

Figure 9 and Figure 10 in the below show how many messages are received in one packet transmission time unit by at least how many of the receivers for 1-persistent CSMA in stationary and in non-stationary settings respectively.

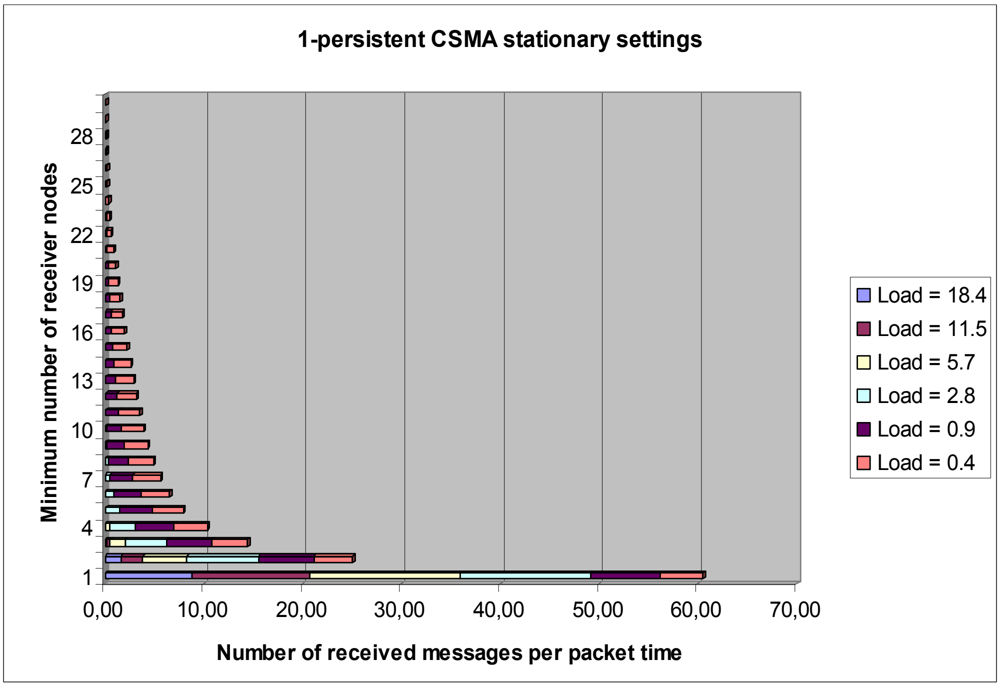


**Figure 9** Number of received messages per packet time versus minimum number of receiver nodes for 1-persistent CSMA in stationary settings with different traffic load conditions

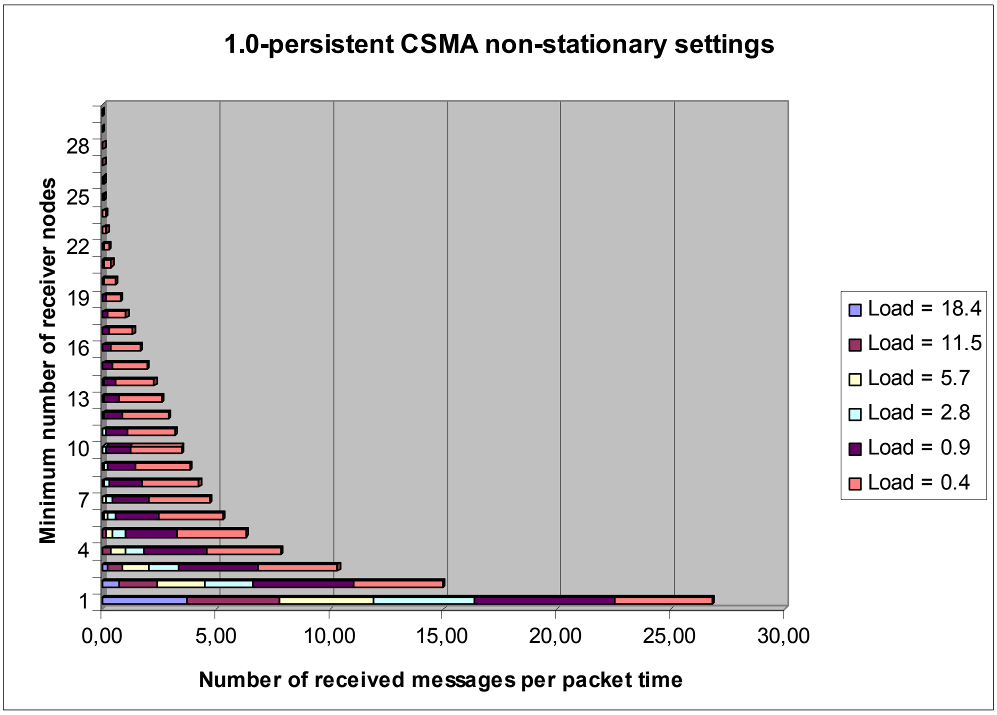


**Figure 10** Number of received messages per packet time versus minimum number of receiver nodes for 1-persistent CSMA in non-stationary settings with different traffic load conditions

In these figures it is seen that when the packet traffic is sparse there are more nodes that receive the same packet which means as the packet traffic becomes denser, the number of receivers decrease. When Figure 9 and Figure 10 are compared it is also obvious that there is a considerable difference between the number of received messages in stationary and in non-stationary settings.

Almost same results are also valid for 0.75-persistent CSMA, 0.5-persistent CSMA and 0.25-persistent CSMA algorithms which prove that there is a problem when the mobility is introduced for P-persistent CSMA algorithm. The related figures for these algorithms are represented in Appendix A

The only difference in these figures is, In Figure 18 which shows the 0.75-persistent CSMA, in stationary setting the saturation point of the network is also seen but it is not seen in Figure 19 and Figure 20 which show the 0.5-persistent and 0.25-persistent CSMA respectively. To see the saturation point in these figures, the average traffic load must be increased more. Because of the limited resources, it couldn't be increased further in this project.

It is seen that all of them is affected seriously with the mobility. When compared the results of P-persistent CSMA for different P values, the effect of mobility is almost same on all of the algorithms so it can not be concluded as the effect of mobility is changing for different P values.

After realizing the problem in P-persistent CSMA in non-stationary settings, the modified algorithm is implemented and the experiments are conducted. Figure 11 shows the result for the original 1-persistent algorithm in stationary, non-stationary settings and for the modified algorithm.

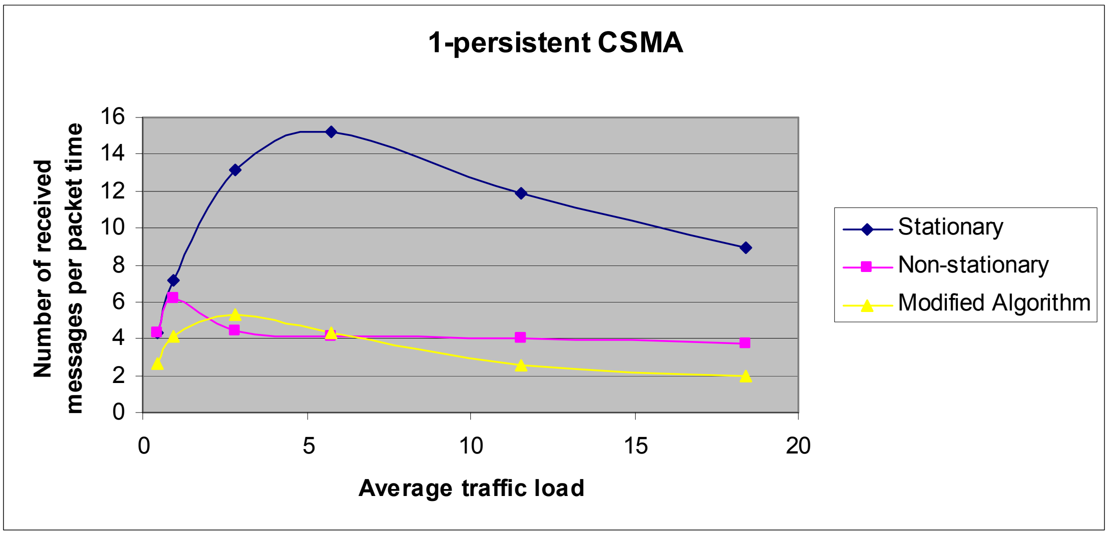


**Figure 11** Number of received messages per packet time versus average traffic load in stationary, non-stationary settings and modified algorithm for 1-persistent CSMA

In modified algorithm, there is a saturation point of the network also that can be seen from Figure 11 and it is saturated earlier than the stationary settings. In all conditions of the average traffic load, as presented in Figure 11, the number of received messages in modified algorithm is much lower than the stationary settings; it did not increased with the modification implemented in this project when compared with the non-stationary settings.

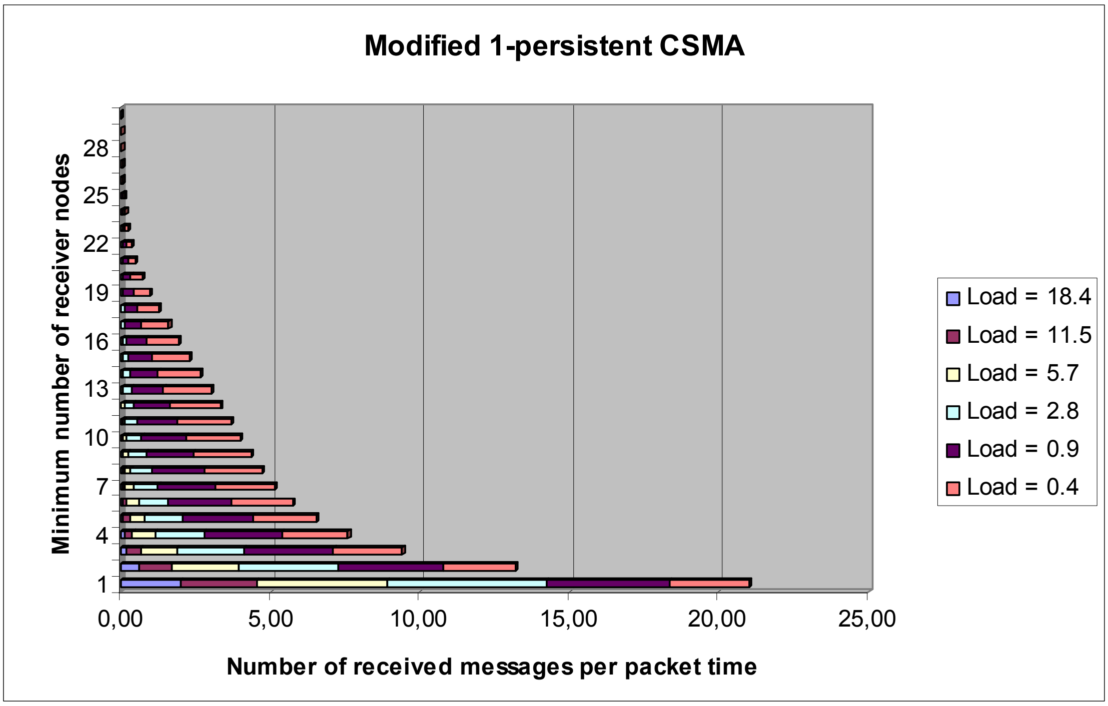


**Figure 12** Number of received messages per packet time versus minimum number of receiver nodes for modified version of 1-persistent CSMA with different traffic load conditions

Figure 12 in the above show how many messages are received in one packet transmission time unit by at least how many of the receivers for modified version of 1-persistent CSMA. When Figure 10 and Figure 9 are compared it is also seen that there is not any improvement in the number of received messages for modified algorithm.

Almost same results are also valid for 0.75-persistent CSMA, 0.5-persistent CSMA and 0.25-persistent CSMA algorithms. This proves that the proposed modification algorithm is not working on the original P-persistent CSMA algorithm. The related figures for these algorithms are represented in Appendix A

The reason for these unsuccessful results is messages are accumulated while the nodes are waiting for their correct time period to make the transmission. Then every node, traveling in the same direction, try to access the channel at the same time when the

correct time period is come. This reason increases the probability of the collision and decreases the throughput of the network.
It is proved that there is a problem with the existing MAC algorithm for VANETs in non-stationary settings but the modification algorithm proposed in this project can not be a solution to this problem. So it is required to search for new solutions.

In the remaining part of this section the results of the Distributed TDMA slot assignment algorithm are presented. We wonder if the same modification mentality is working for this algorithm or not. Figure 13 shows the number of received messages per packet time with respect to increasing average traffic load for distributed TDMA slot assignment algorithm in stationary and in non-stationary settings.

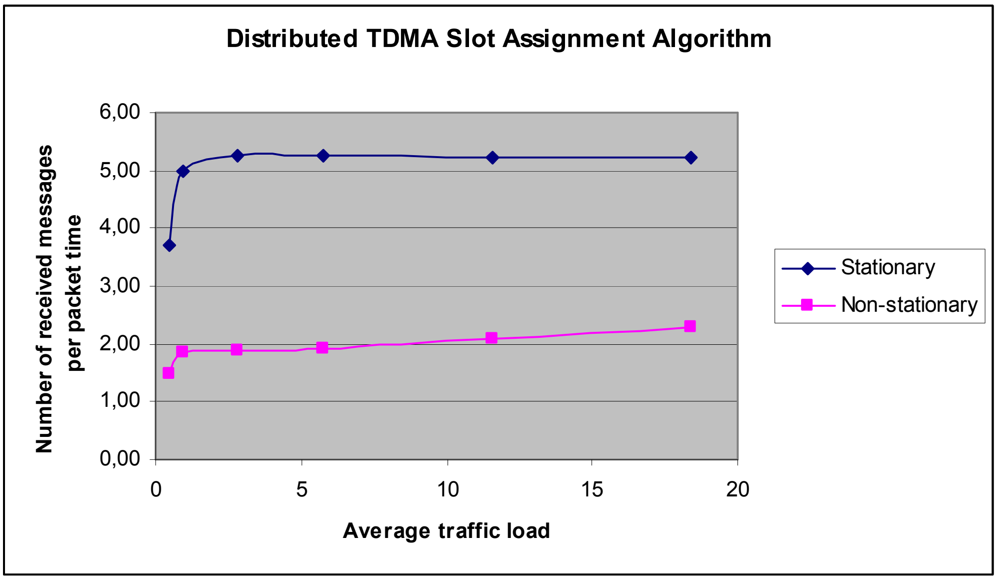


**Figure 13** Number of received messages per packet time versus average traffic load in stationary, non-stationary settings for distributed TDMA slot assignment algorithm

In both settings, at first with increasing packet send rate of the nodes number of received messages is increasing also. But after some point the number of received messages is not changing significantly with the increasing average traffic load.

In all conditions of the average traffic load, it can be easily seen that the number of received messages in non-stationary setting is significantly lower than stationary settings. This result proves that there is a problem with this algorithm also when the mobility is introduced.

Figure 14 and Figure 15 in the below show how many messages are received in one packet transmission time unit by at least how many of the receivers for distributed TDMA slot assignment algorithm in stationary and in non-stationary settings respectively.

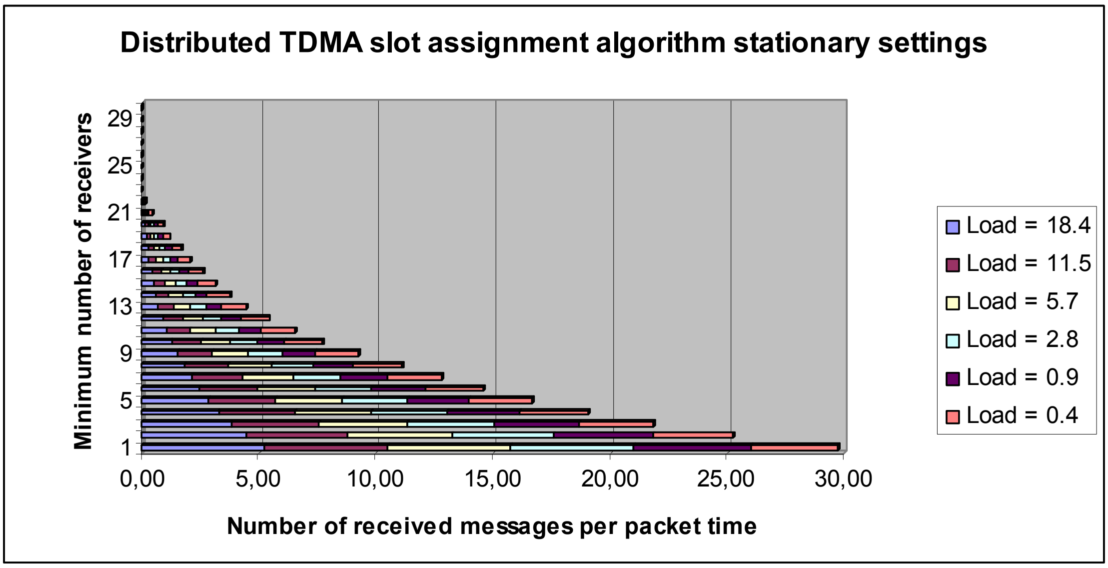


**Figure 14** Number of received messages per packet time versus minimum number of receiver nodes for distributed TDMA slot assignment algorithm in stationary settings with different traffic load conditions

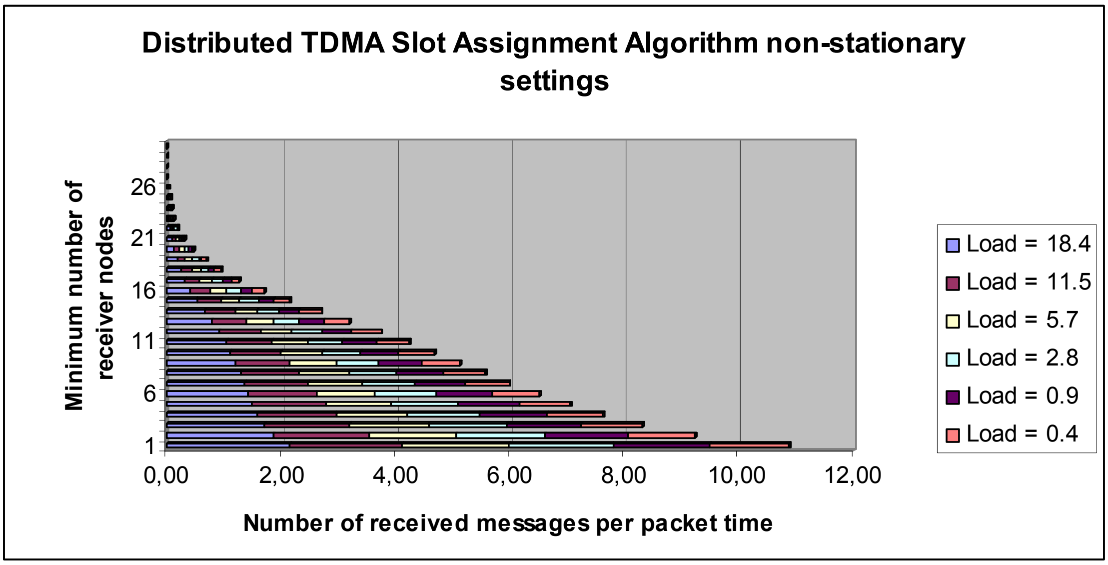


**Figure 15** Number of received messages per packet time versus minimum number of receiver nodes for distributed TDMA slot assignment algorithm in non-stationary settings with different traffic load conditions

In these figures it is again seen that as the packet traffic become denser the number of receivers decrease. When Figure 14 and Figure 15 are compared it is also obvious that there is a considerable difference between the number of received messages in stationary and in non-stationary settings.

After realizing the realizing the serious decrease in the throughput with the introduced mobility for distributed TDMA slot assignment algorithm, the modified algorithm is implemented and the experiments are conducted. Figure 16 shows the result for the original distributed TDMA slot assignment algorithm in stationary, non-stationary settings and for the modified algorithm.

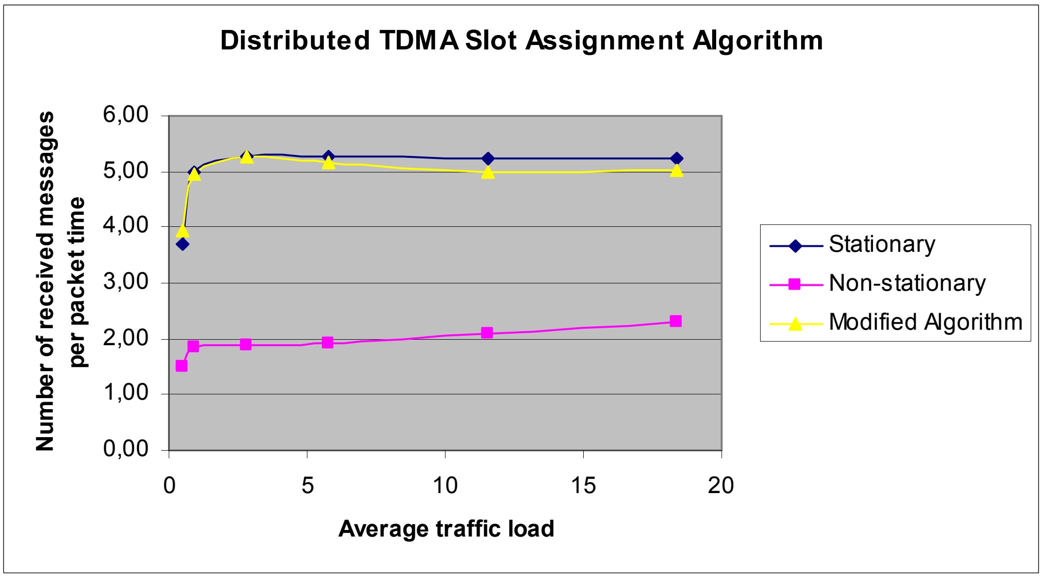


**Figure 16** Number of received messages per packet time versus average traffic load in stationary, non-stationary settings and modified algorithm for distributed TDMA slot assignment algorithm

In modified algorithm, at first with increasing packet send rate of the nodes number of received messages is increasing also. But after some point the number of received messages is not changing significantly with the increasing average traffic load. Most importantly, there is an observable increase in the number of received messages with the modification. The results of the modified algorithm in non-stationary settings are almost same with the results of the original algorithm in stationary settings.

Figure 17 in the below show how many messages are received in one packet transmission time unit by at least how many of the receivers for modified version of distributed TDMA slot assignment algorithm. When Figure 15 and Figure 17 are compared it is also seen that there is a significant improvement in the number of received messages for modified algorithm.

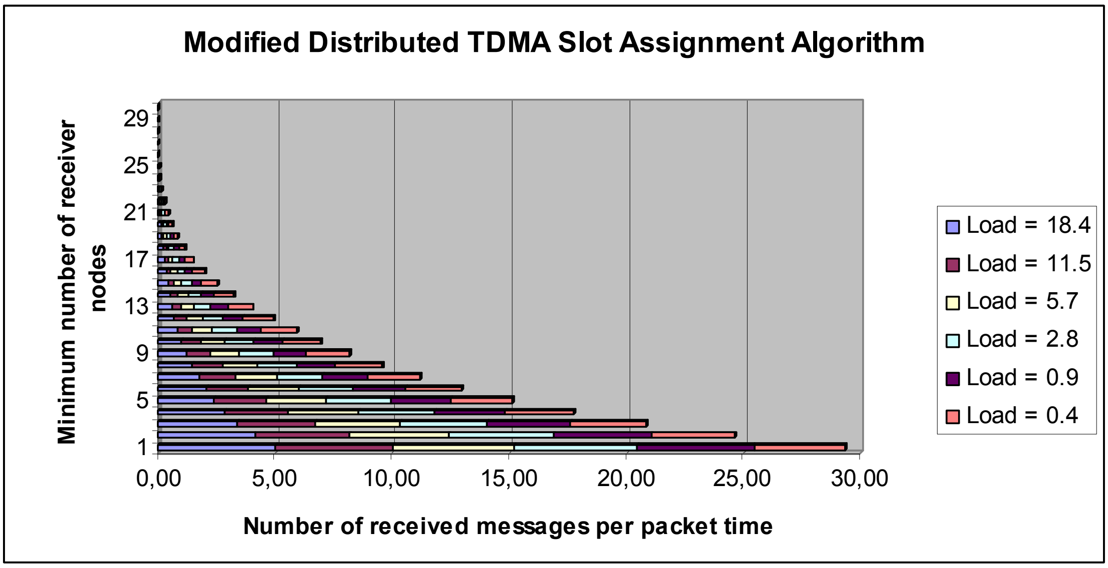


**Figure 17** Number of received messages per packet time versus minimum number of receiver nodes for modified version of distributed TDMA slot assignment algorithm with different traffic load conditions

The purpose of the modification was to surpass the effect of mobility. So, the throughput would not decrease with the introduction of mobility in the network. After looking the results for distributed TDMA assignment algorithm, it is easily seen that the results of modified algorithm in non-stationary settings are almost same with the results of the original algorithm in stationary settings. We can conclude that the modification is working correctly for distributed TDMA assignment algorithm. Mobility has not big effect on the throughput of the network for the modified version of the algorithm.

It can be said that, the explained modification technique is working on some algorithms like distributed TDMA assignment algorithm, but not on all of them. The difference between the p-persistent CSMA and the distributed TDMA assignment algorithm is: p-persistent CSMA is not slot based algorithm but the distributed TDMA assignment algorithm is. So it may be said that this modification technique is more likely working on the slot based algorithms.

# 6. FUTURE WORK

In the modified algorithm we have the information of how many of the cars are traveling in each direction. In addition, the nodes are placed on the road uniformly at random. Also, we assumed that the ratio of the cars traveling in each direction is almost same in every part of the road. So the bandwidth allocation ratio is kept constant in every part of the road. In this setup it is shown that the throughput of the original distributed TDMA slot assignment algorithm is improved in the modified algorithm for non-stationary settings.

For the distributed TDMA slot assignment algorithm, one may want to make the modified algorithm adaptive to the traffic conditions. This means that the algorithm allocates different percentages of the bandwidth in different part of the road. This means that the bandwidth allocation can be made dynamically by the vehicles during the system execution. This bandwidth allocation will be made according to the ratio of the cars traveling in each direction. By this modification, it will be possible to have different bandwidth allocation ratios in different part of the roads.

To implement this algorithm, again the nodes will store a neighbor table. In this table the nodes store the permanent neighbors traveling in same direction. In order to define their permanent neighbors, nodes will use an "I am alive" messages. After defined their permanent neighbors, they will start to communicate with each other by application messages. If the nodes sense another node that is not in the permanent neighbor table, this means there is another group of cars coming from other direction. Then, both groups share the "number of cars in the group" information with each other. So the bandwidth can be shared between each group according to the ratio of the number of cars traveling in each direction.

The advantage of this modification is the algorithm will be adapted to the dynamic traffic conditions. After implementation of this modification, the fairness and the adaptive features can be used for this algorithm.

# 7. CONCLUSIONS

The work presented in this thesis is focused on the problem of the existing MAC algorithms in non-stationary settings. In most of the existing MAC algorithms the mobility of all nodes did not considered. This project studies the modification for the existing MAC algorithms and implementation of this modification.

P-persistent CSMA and distributed TDMA slot assignment algorithm are tested in this project. Four different p values are considered for the p-persistent algorithm. Different traffic loads are considered also in order to discover the relationship between the throughput and traffic load. Both algorithms are firstly tested in stationary and non-stationary settings. For both algorithms, it is observed that, when the nodes are mobile there is an important decrease in the throughput of the network. Then a modification is considered for the existing MAC algorithms for non-stationary settings. The purpose of the modification was to surpass the effect of mobility. So, the throughput would not decrease with the introduction of mobility in the network.

For the modified version of the p-persistent algorithm, it is seen that the throughput of the network did not increase. The throughput results for the modified algorithm is still much lower than the stationary settings of the original algorithm. So, for p-persistent algorithm it is proved that there is a problem with the existing MAC algorithm in non-stationary settings, however the modification algorithm proposed in this project can not be a solution to this problem. It is required to search for new solutions.

For the distributed TDMA assignment algorithm, it is easily seen that the modified algorithm increased the throughput of the network in non-stationary settings. The results of modified algorithm in non-stationary settings are almost same with the results of the original algorithm in stationary settings. It can be concluded that the modification is working correctly for distributed TDMA slot assignment algorithm. The modified algorithm beat the effect of mobility.

It can be said that, the explained modification technique is working on some algorithms like distributed TDMA assignment algorithm, but not on all of them. The difference between the p-persistent CSMA and the distributed TDMA assignment algorithm is: p-persistent CSMA is not slot based algorithm but the distributed TDMA assignment algorithm is. So it may be said that this modification technique is more likely working on the slot based algorithms.

# APPENDIXES

## A) Figures for p-persistent CSMA algorithm

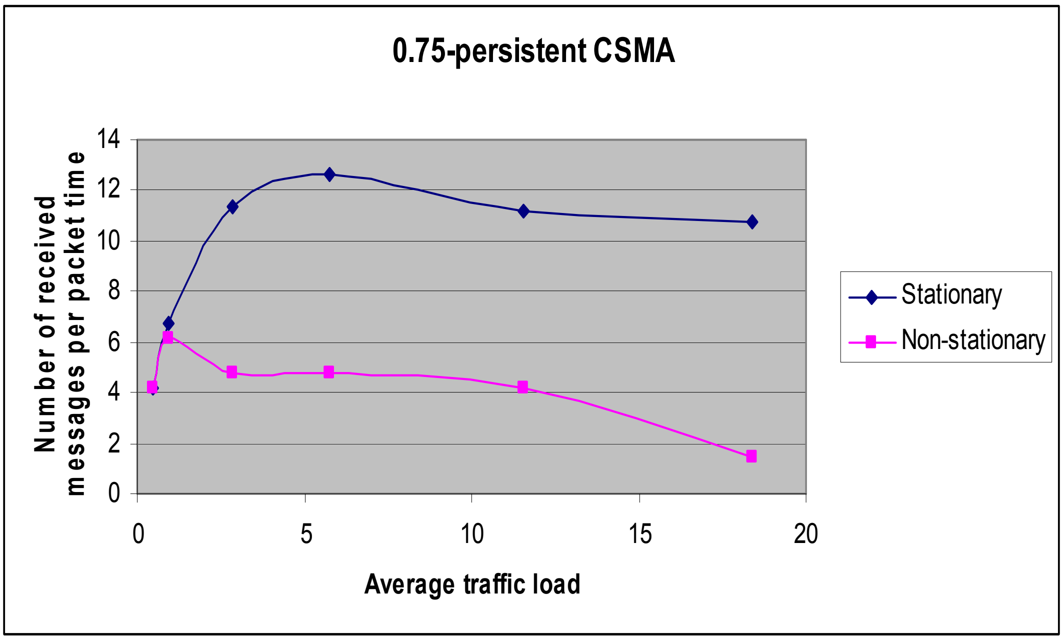


**Figure 18** Number of received messages per packet time versus average traffic load in stationary and in non-stationary settings for 0.75-persistent CSMA

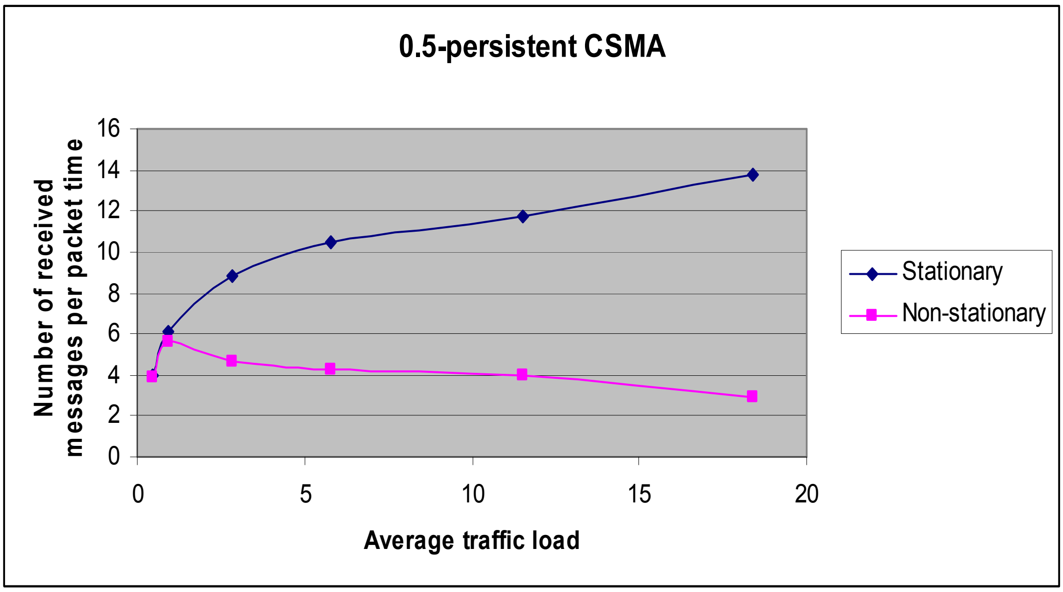


**Figure 19** Number of received messages per packet time versus average traffic load in stationary and in non-stationary settings for 0.5-persistent CSMA

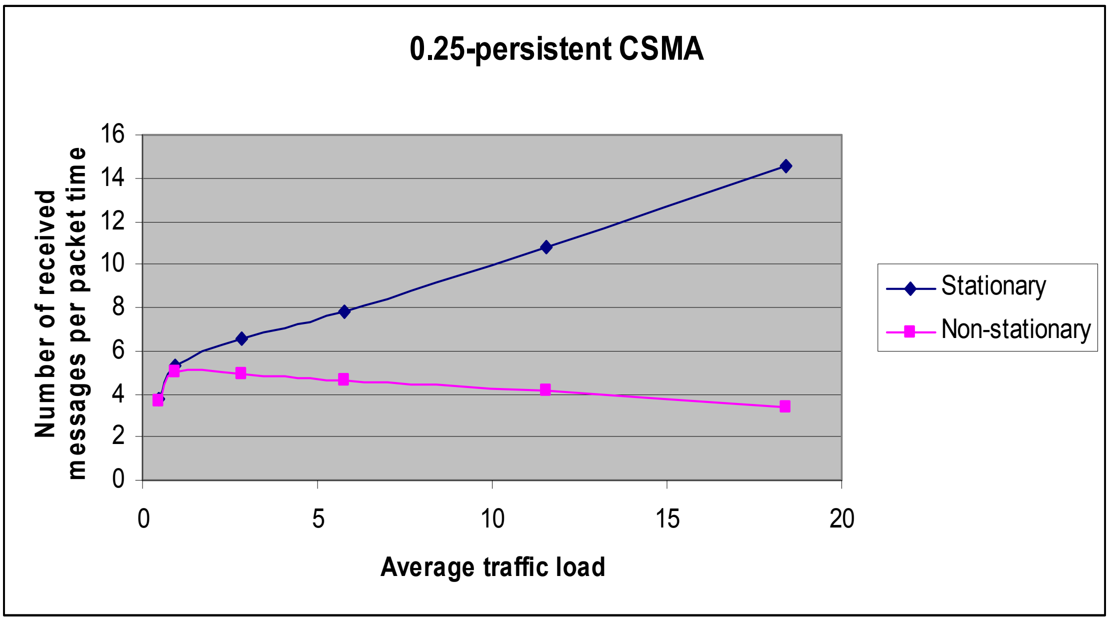


**Figure 20** Number of received messages per packet time versus average traffic load in stationary and in non-stationary settings for 0.25-persistent CSMA

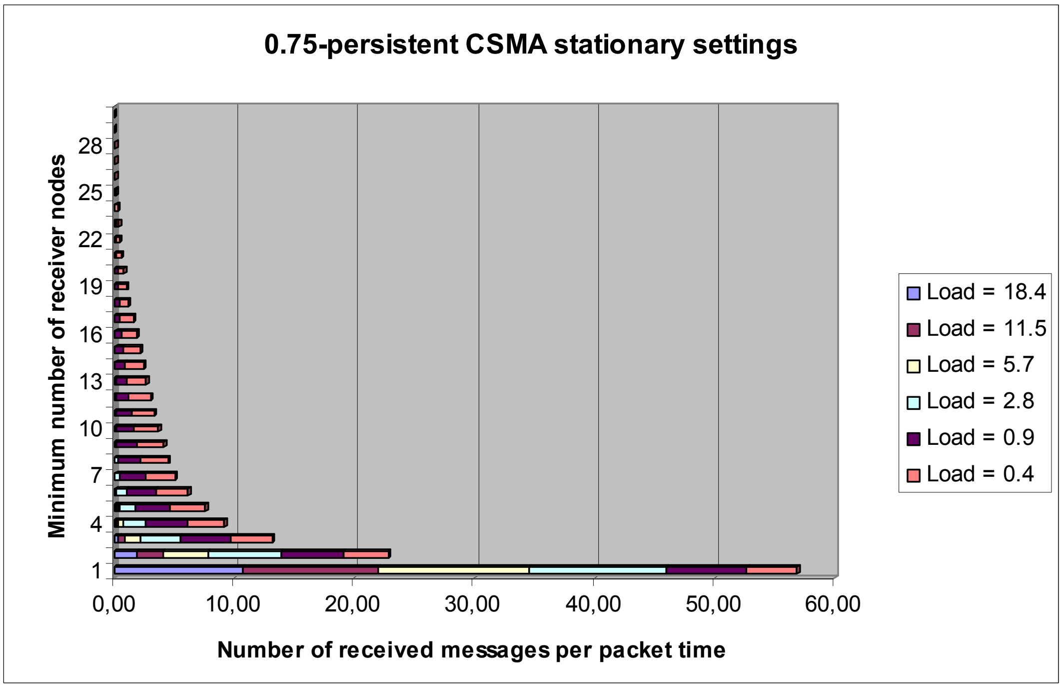


**Figure 21** Number of received messages per packet time versus minimum number of receiver nodes for 0.75-persistent CSMA in stationary settings with different traffic load conditions

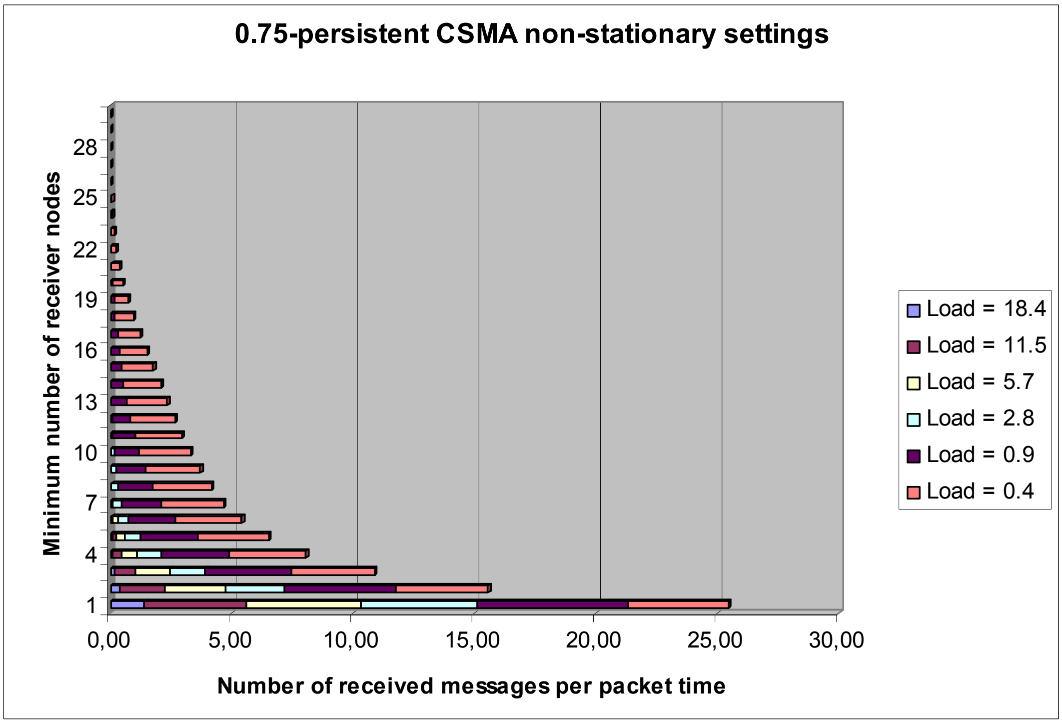


**Figure 22** Number of received messages per packet time versus minimum number of receiver nodes for 0.75-persistent CSMA in non-stationary settings with different traffic load conditions

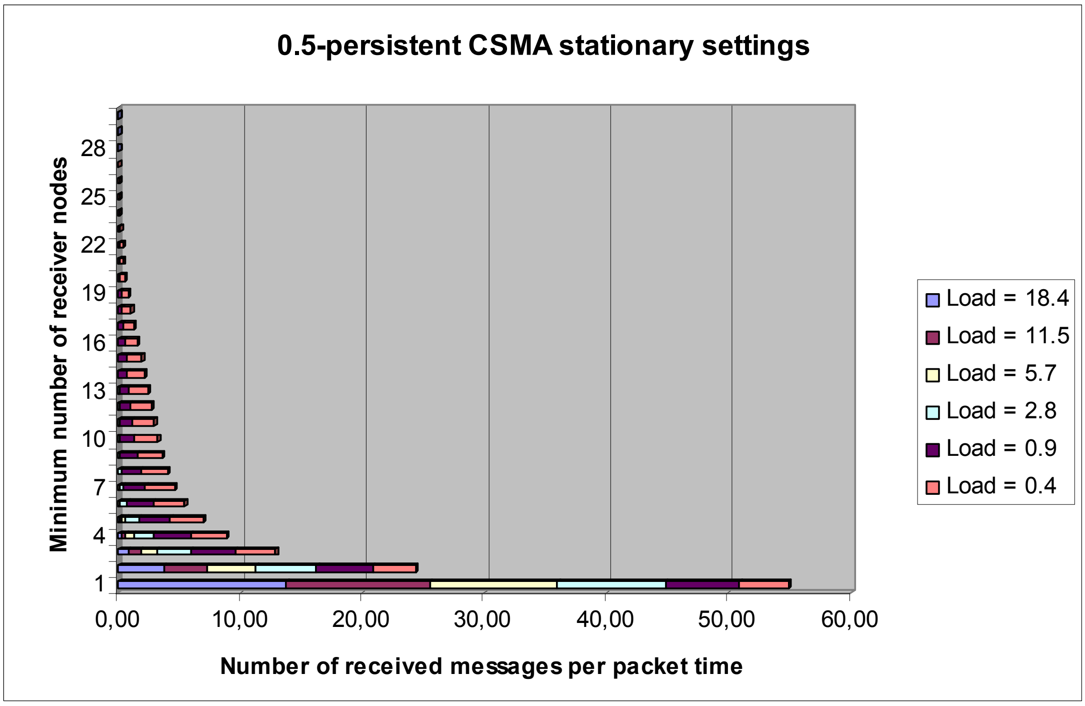


**Figure 23** Number of received messages per packet time versus minimum number of receiver nodes for 0.5-persistent CSMA in stationary settings with different traffic load conditions

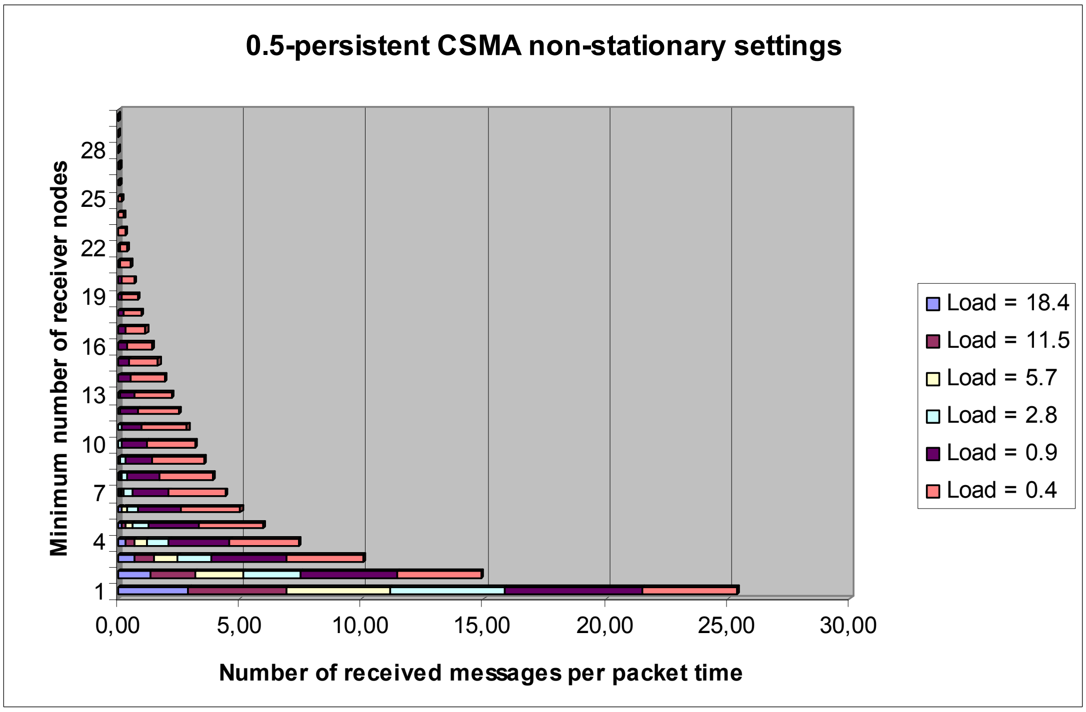


**Figure 24** Number of received messages per packet time versus minimum number of receiver nodes for 0.5-persistent CSMA in non-stationary settings with different traffic load conditions

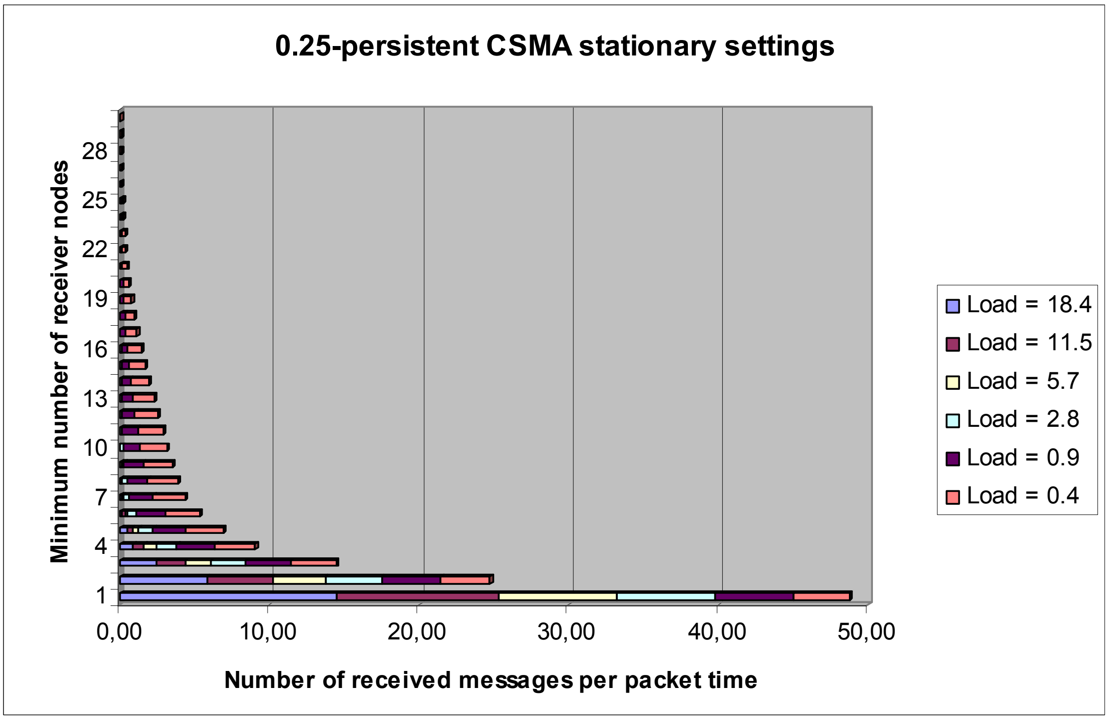


**Figure 25** Number of received messages per packet time versus minimum number of receiver nodes for 0.25-persistent CSMA in stationary settings with different traffic load conditions

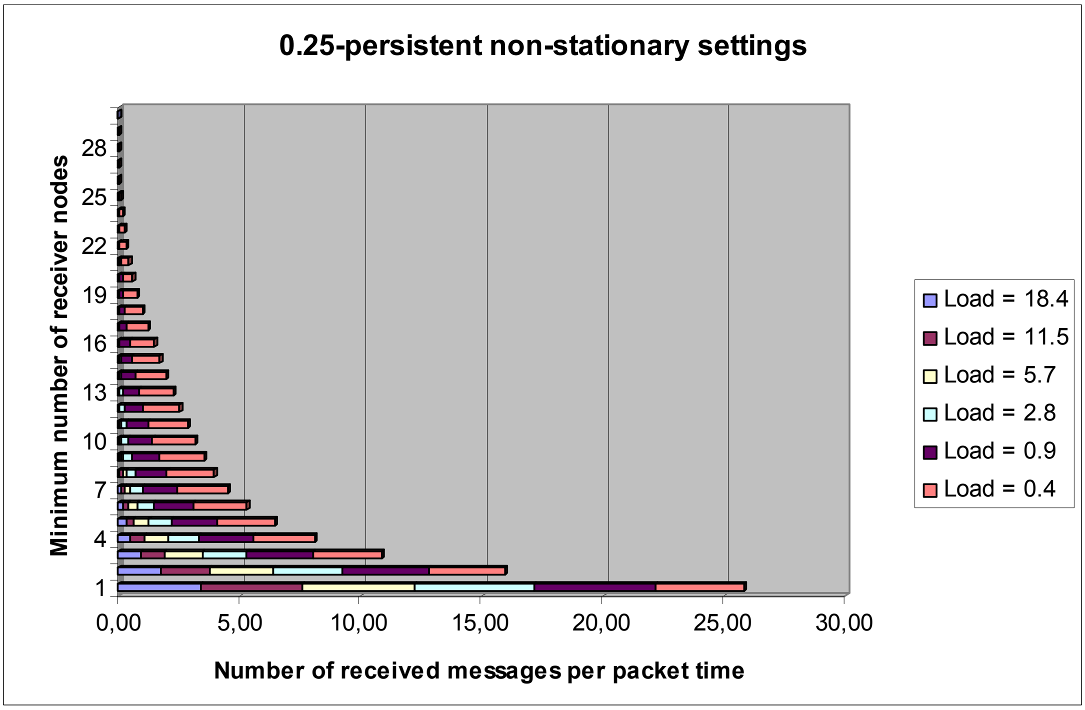


**Figure 26** Number of received messages per packet time versus minimum number of receiver nodes for 0.25-persistent CSMA in non-stationary settings with different traffic load conditions

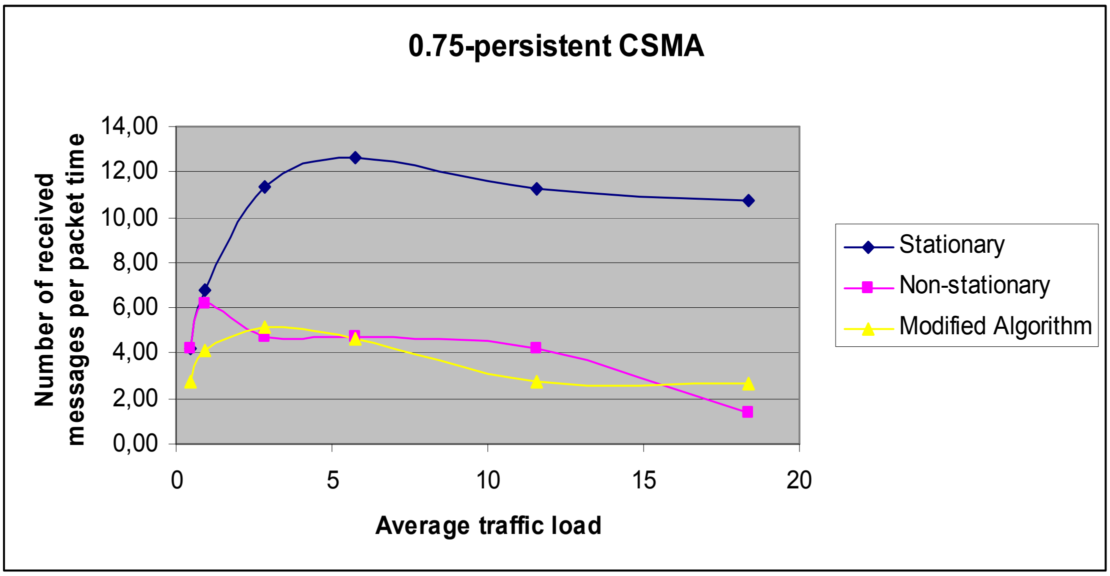


**Figure 27** Number of received messages per packet time versus average traffic load in stationary, non-stationary settings and modified algorithm for 0.75-persistent CSMA

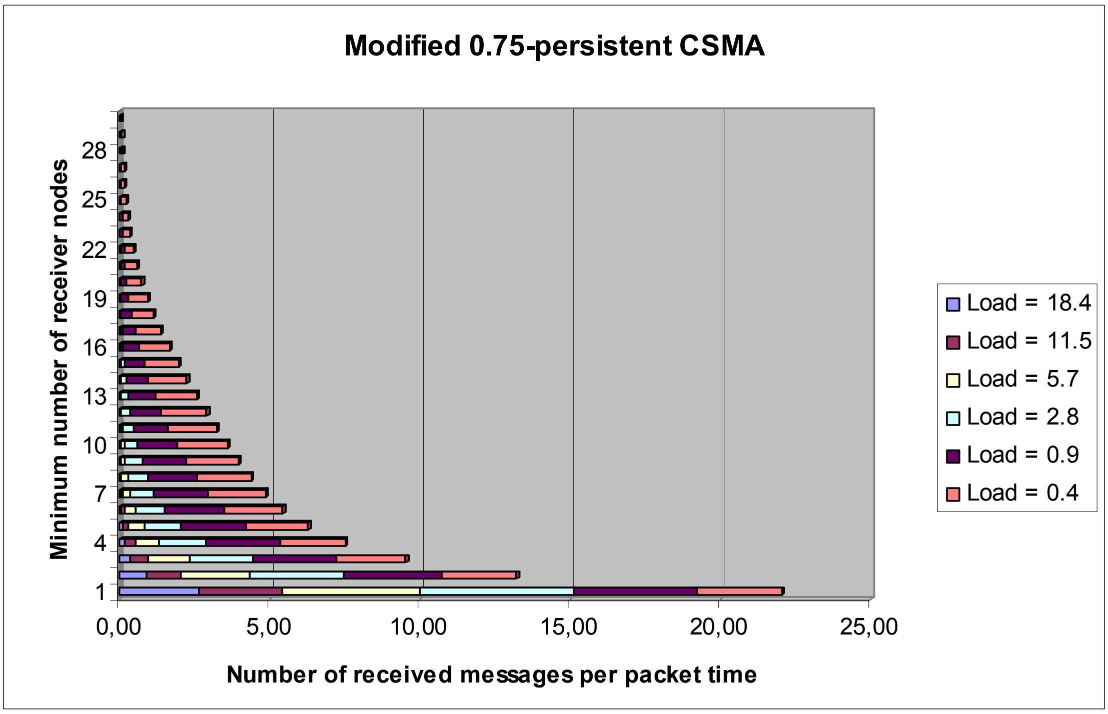


**Figure 28** Number of received messages per packet time versus minimum number of receiver nodes for modified version of 075-persistent CSMA with different traffic load conditions

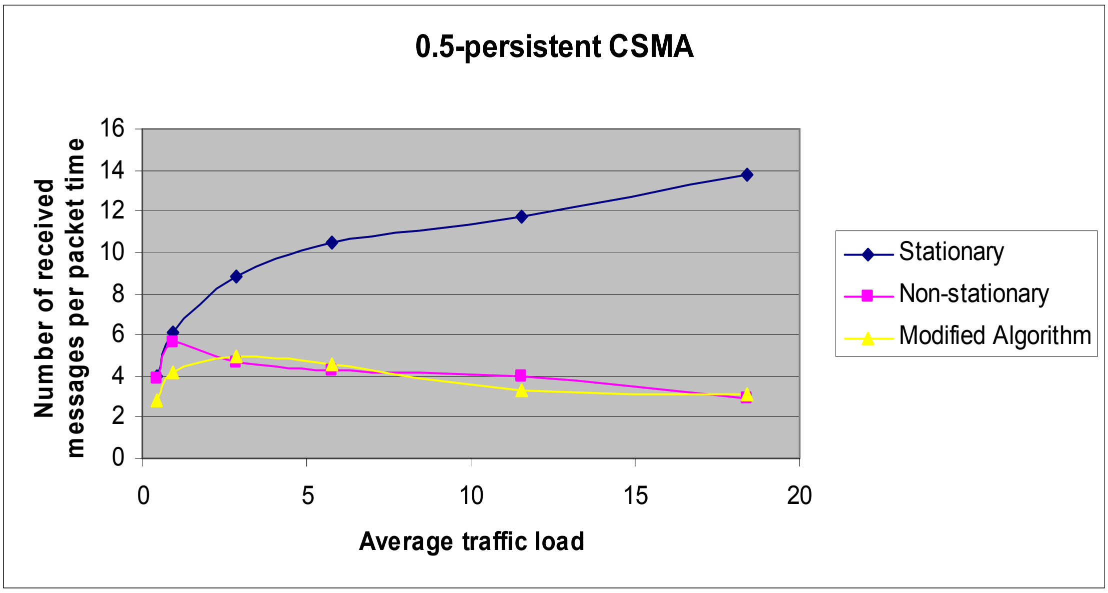


**Figure 29** Number of received messages per packet time versus average traffic load in stationary, non-stationary settings and modified algorithm for 0.5-persistent CSMA

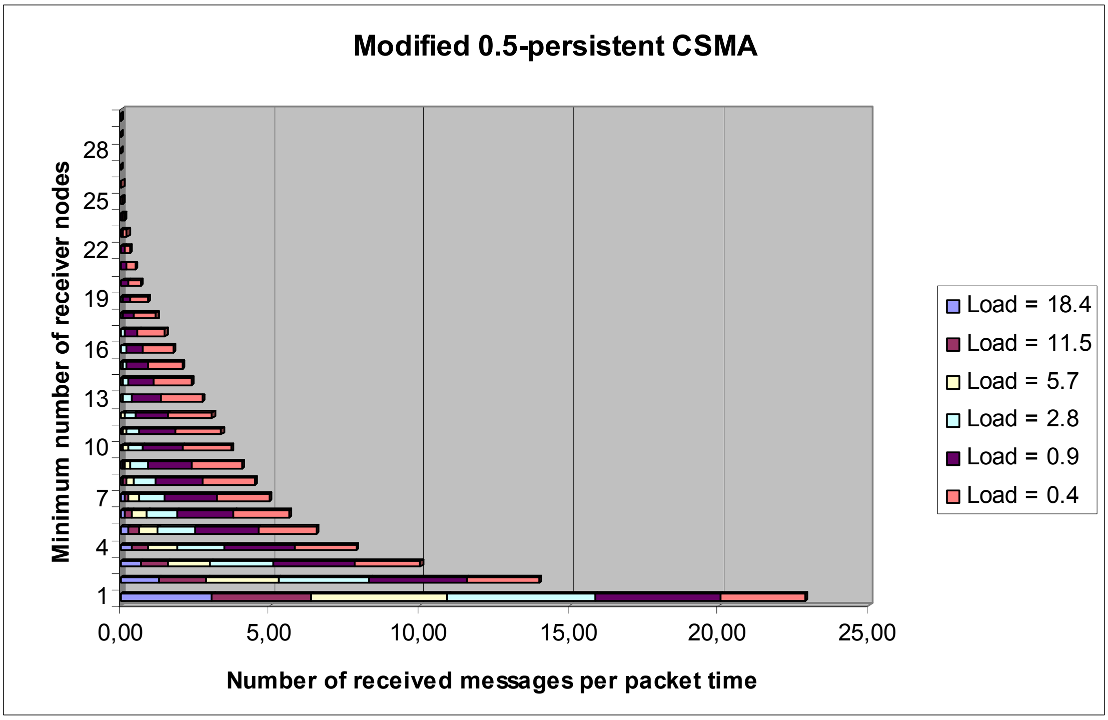


**Figure 30** Number of received messages per packet time versus minimum number of receiver nodes for modified version of 05-persistent CSMA with different traffic load conditions

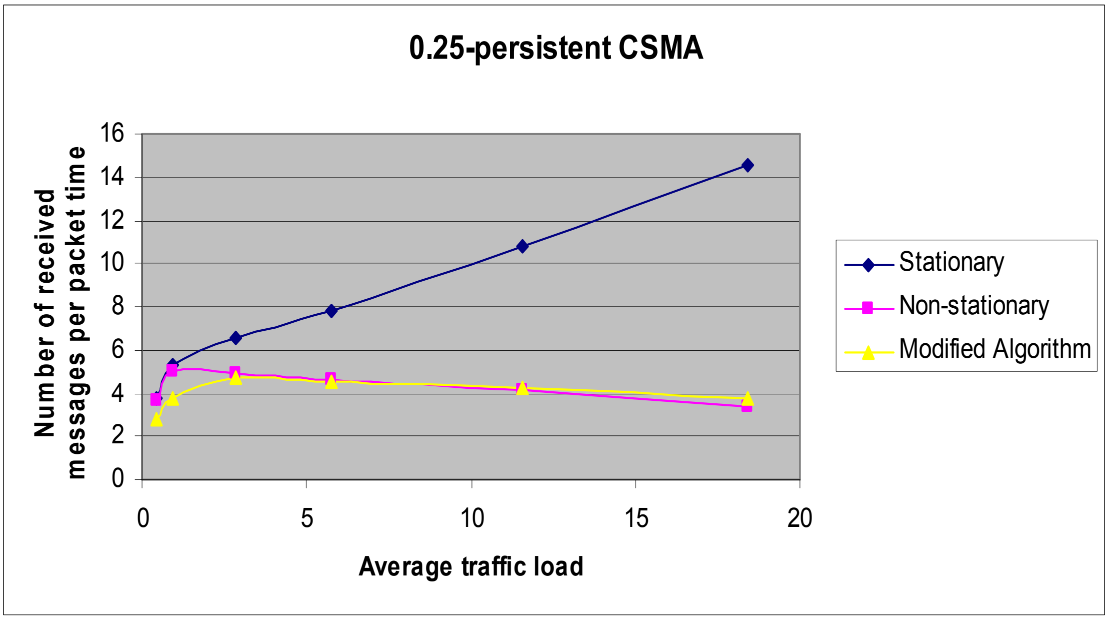


**Figure 31** Number of received messages per packet time versus average traffic load in stationary, non-stationary settings and modified algorithm for 0.25-persistent CSMA

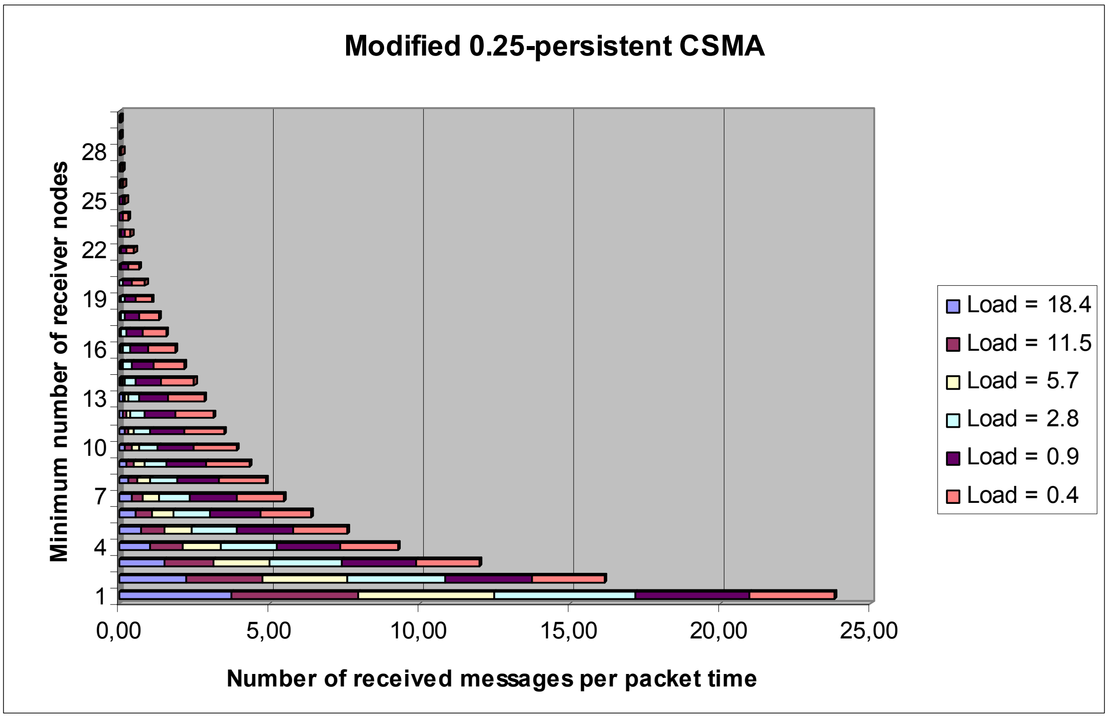


**Figure 32** Number of received messages per packet time versus minimum number of receiver nodes for modified version of 025-persistent CSMA with different traffic load conditions

## B) Calculation of the expected number of neighbors

The expected number of neighbors is changing according to the different positions of the vehicle. Figure 33 shows the different positions of the vehicle for the different values of x [0, 2500]. Since the size of the road is 5000m, 2500m is exactly the middle of the road. So, in the other parts of the road the calculation will be same also.

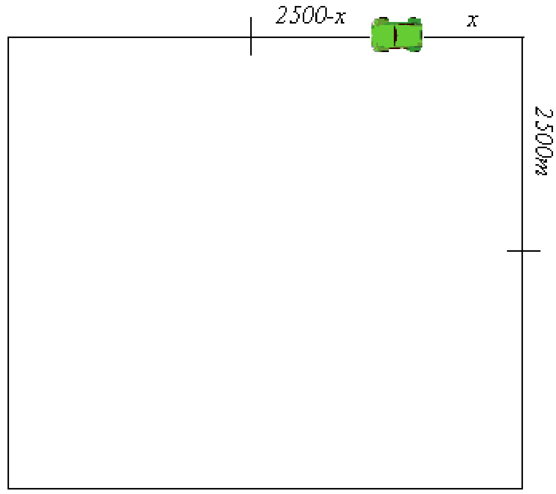


**Figure 33** Different positions of the vehicle in the square road

The expected number of neighbors can be calculated as can be seen in

Size of the field: 4x5000meter

- Total number of nodes: 200
- Range of transmission: 880meter

Table 2. First, it is calculated in every different position of the vehicle and then the averages of these results are taken which give the expected number of neighbors.

- Size of the field: 4x5000meter
- Total number of nodes: 200
- Range of transmission: 880meter

**Table 2** Sample code to calculate the expected number of neighbors

```
sum1=0;
sum2=0;
field_size=4*5000;
total_node_number=200;
range_of_transmission = 880;

for x = 0:1:880

    sum1 = sum1 + x + sqrt(880^2 - x^2) + 880;
end

for x = 881:1:2500

    sum2 = sum2 + (880*2);
end

average=(sum1+sum2)/2501;
result= (average/field_size)*total_node_number;
```

**Result =18.48**

After obtaining the expected number of neighbors, the average traffic load can be calculated for different number of transmission attempts of one node in one packet time.

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