

An All-IP VANET architecture supported on R2V and V2V communication through 802.11

António Fonseca, *Student Member, IEEE*

Abstract—This paper proposes an All-IP VANET architecture where the vehicles end-systems use a single interface to communicate to the roadside and to the other vehicles. In our architecture APs are placed in junctions and will be used to forward all the traffic of their neighbourhood so that propagation problems caused by obstacles, such as buildings can be avoided.

Using a location-based routing assures a low overhead as it avoids flooding the network with routing information. An extension to the GPSR protocol have been proposed to support the mandatory selection of the AP, whenever it is near the destination than the node itself.

In spite of the advantages of using the AP to improve connectivity, it may represent a performance bottleneck, specially when a significant amount of traffic circulates in its vicinity. To overcome this problem two complementary extensions have been proposed for the MAC protocol of the AP, aiming at improving its priority to access the wireless medium: stalling the Congestion Window of the AP, and/or decreasing DIFS near to SIFS.

Simulation results using CBR traffic have shown the advantages of our MAC extensions, as the Packet Delivery Ratio have increased. Concerning TCP traffic, no significant differences are foreseen, when compared to the results achieved with the standard MAC with the GPSR extensions.

Index Terms—VANET, MAC

I. INTRODUCTION

Recent advances in wireless technologies and embedded systems extended the use of communications to new domains. Taking advantages of such technological advances, vehicle and equipment manufacturers have recognised the opportunity of enhancing the surface transportation by using the communication capabilities of the Vehicular Ad hoc Network (VANET) to offer an Intelligent Transportation System (ITS) to the drivers.

Due to the well-defined mobility pattern of the nodes and characteristics of the surrounding environment, most of the solutions that have been proposed for Mobile Ad hoc Network (MANET) are not suitable for VANET [1][2]. Thus, a significant scientific effort is being put in the definition of complete network architectures [3][4], new standards for protocol stacks, specific solutions for routing [5] or for Medium Access Control (MAC) [6].

Very complete and visionary approaches presented so far are based on complex and expensive technological solutions. Some of them propose the use of different access technologies to support Vehicle-to-Vehicle (V2V) communication and Road-to-Vehicle (R2V) communication: this is the case of [7] that proposes the use of WiFi and WiMax technologies or [8] that uses ZigBee and WiFi as access technologies. The use of an additional non-IP pro-

ocol stack is also under consideration, as defined in the German project Network on Wheels [9], or on the standard Wireless Access for Vehicular Environments (WAVE) [10][11][12][13].

The use of different access technologies or the design of new protocol stacks may present several advantages. Nevertheless, in both cases the complexity of the vehicles end-systems will increase significantly, having a major impact on the cost of the end-systems and, consequently, on the widespread dissemination of the technology.

Our goal is to design and evaluate a VANET architecture that offers an adequate level of performance at a reduced cost. Thus, our main premises are to use:

All-IP network – reduces the cost of vehicles end-systems, by being able to use any IP-based end-system, equipped with a single and widely deployed network interface, such as 802.11;

Infra-structured VANET – minimises the impact of inadequate propagation conditions or insufficient number of connectable vehicles, by placing some Access Points (APs) in specific places of the environment, such as junctions and corners;

Low overhead protocols – guarantees an efficient data delivery, by using a low overhead routing protocol and an efficient Medium Access Control (MAC) mechanism.

To validate our performance two main metrics are considered: the Packet Delivery Ratio (PDR) of Constant Bit Rate (CBR) traffic and the Throughput (TP) of TCP protocol.

The remaining paper is organised as follows: section 2 describes the related work, focusing some relevant aspects: network architecture, routing and MAC protocols; section 3 describes our solution, comprising the network architecture, routing and MAC layer; section 4 presents the simulation results and, finally, section 5 the conclusions and the future work.

II. RELATED WORK

A. Network architecture

There are two basic VANETs architecture: with and without infrastructure.

In a VANET without infrastructure, each vehicle is equipped with a wireless interface which is used to support the communication between vehicles [14][15] so that when a vehicle wants to send a message to a distant node, it only uses the other vehicles in the way to forward the message. When there are not enough vehicles to assure connectivity or, when there are plenty of vehicles but none moving towards the destination, packets may not be for-

warded. Although its simplicity, VANET without infrastructure might fail to guarantee the level of performance required by most of the services. Moreover, in an urban environment propagation is extremely affected by buildings and obstacles, specially in junctions, restricting even more the connectivity.

To overcome the connectivity problems caused by an insufficient number of connectable vehicles, an infra-structured VANET may be used, where APs located in specific places of the environment route packets to the destination.

If wired backbone is used to interconnect the routers, most of the traffic is transferred to it and traditional applications and services are available to the users. Nevertheless, this is a very expensive solution as it requires the installation of a physical infrastructure along the routes, highways, roads connecting distant places or streets in an urban environment. A less expensive solution is provided if no backbone is used, in which the APs are only used as relay nodes to achieve better performance.

B. Routing protocols

A wide variety of routing protocols ranging from adaptation of classical approaches to biological inspired models have been used in VANET [16], [17]. Available research work have shown that position-based protocols are more efficient, having less overhead than the other classes of protocols [18] because they use the position of the destination node to make routing decisions, retrieved form a location service, and thus the next hop selection is very simple and reliable. Examples of such kind of routing are the Geographic Source Routing (GSR) [19], Greedy Perimeter Stateless Routing (GPSR) [20] and Greedy Perimeter Coordinator Routing (GPCR) [21].

In GSR, the source vehicle chooses an end-to-end route to the destination. Since the link breakage might be too high due to the high and unpredictable mobility of the nodes, defining an end-to-end route is not adequate. To solve this problem, in GPSR each forwarding node sends the packet to its one-hop neighbour that is closer to the destination node, using a mechanism called as simple greedy forwarding. Although achieving better performance than GSR, GPSR still present problems, specially in junctions in which buildings and other obstacles interfere with the communication process. This problem has been solved by GPCR through the selection of the vehicles in the middle of a junction (coordinator) as the next-hop neighbour, independently of its proximity to the destination. The use of coordinator depends on the existence of a node crossing a junction when needed. Thus, the best solution is to use GPSR but with APs in junctions to act as the GPCR coordinators, so that a coordinator is always available. Thus, the AP will preferably be selected as next-hop and thus, it might represent a performance bottleneck, unless a more frequent access to the medium is given to it.

C. Medium Access Control mechanisms

In the previous section, we conclude that enhancements on the MAC layer are needed, in order to allow the fixed wireless routers to have a more frequent access to the medium.

Most of the available medium access protocols, like the standard and widely deployed IEEE 802.11 with Distributed Coordination Function (DCF), are supported on the Carrier Sense Multiple Access (CSMA) paradigm, in which the sending node only starts the transmission after sensing the medium idle. When detecting a collision, the node back-off for a random time that depends on the value of the Congestion Window (CW). As all the nodes behave in a similar way, this type of MAC is not adequate because no distinction between the APs and the other nodes is possible. These distinction can be done when the PCF mode is used, because the AP can control the communication process, by polling the other nodes as used by [22]. Nevertheless, the vehicles are unable to switch between these mode and the DCF. Hence they will be unable to communicate outside the coverage area of the APs.

The best strategy consists of making the AP gain the medium access more frequently without changing the protocol. This can be achieved by adjusting the CW growth or changing the AP Inter Frame Spacing (IFS).

III. ARCHITECTURE

A. General architecture

In order to have a good performance an infra-structured solution will be used, but to keep it cost-effective it will have no backbone. Thus the APs will be placed in junctions to overcome propagation problems due to obstacles and to and to increase connectivity.

As stated before, the cost is even lower if only one wireless interface per vehicle is used and if the technology is a widely spread one such as 802.11.

A modified version of GPSR protocol will be used, in which the wireless fixed routers will be selected as next hop if they are closer to the destination than the current node. The fixed wireless routers also use an enhanced MAC algorithm, which allow them to access the wireless medium more frequently.

Figure 1 illustrates the use of our architecture when two nodes - Node 1 and Node 5 -, out of direct range, establish a communication process. As stated in the figure, Node 1 first sends the packet to the AP and then the AP sends it to Node 3, which is the neighbour node nearest to the destination. Node 3 can reach Node 5 and it delivers the packet directly to it.

GPSR enhanced next hop selection algorithm is described in Algorithm 1.

B. MAC Enhancements

Should Node 2, or any other node in the AP's neighbourhood, starts another session in the same time, and the AP would have to receive and retransmit all the traffic. Our enhanced MAC version will allow it to access the

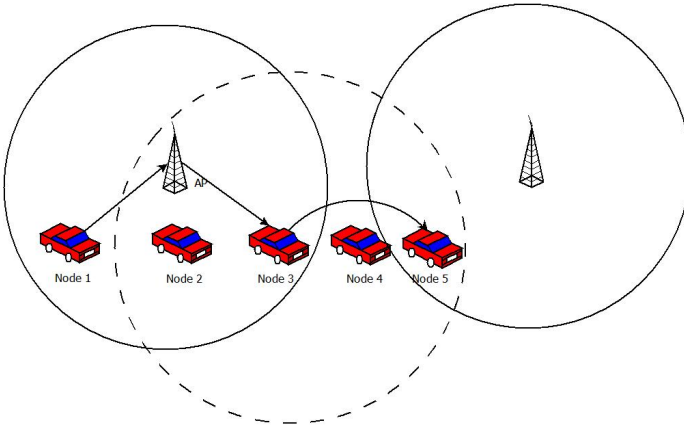


Fig. 1. Communication between nodes 1 and 5

Algorithm 1 Enhanced GPSR next hop selection

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if Is any neighbour an AP then
  Send to AP
else
  if Destination is a neighbour then
    Send to destination
  else
    Send to the neighbour closest to the destination
  end if
end if

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medium faster, either because the CW growth was stalled after collisions, or because a small IFS value is used.

When stalling the value of the CW, if the AP and other node's packet collide, the CW of the mobile node will grow while the CW of the AP will not. This will give more probability for the AP to gain the medium access, allowing them to send data faster.

The value of IFS can be SIFS or DIFS, depending on the type of data being transmitted. According to the standard IEEE 802.11, SIFS is used with control frames (ack) and DIFS with data frames, in order to allow a priority access to the wireless medium for control traffic. One of our enhancements of MAC layer consists in changing the value of IFS to allow the AP to gain access to the medium before any competing mobile node. In order to avoid collisions with control traffic the new AP IFS (DIFS') should be defined so that: $SIFS < DIFS' < DIFS$.

In Figure 2 is represented the IEEE standard 802.11 MAC flowchart. If the CW modification is used, the box named "Increase CW exponentially" is not present, while if the new DIFS' is used, IFS is replaced by a value that matches the above mentioned condition.

IV. SIMULATION STUDIES

A. Simulation scenario

The main goal of our simulations is evaluating how the network performance changes when our VANET architecture is used. We tested this goal using the enhanced version of GPSR, with and without the MAC enhancements.

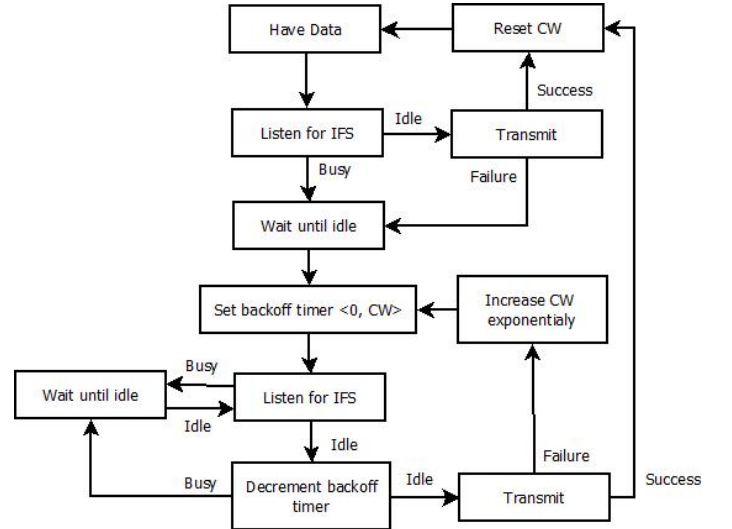


Fig. 2. MAC 802.11 Flowchart

For this, the simulator used was ns-2 version 34 with the GPSR module modified to support our extensions.

In VANETs nodes are not placed randomly, as vehicles follow roads with their restrictions. To take into account this limitations we used a Manhattan street network, where the vehicles are only allowed to move along the roads, changing their directions only at the intersections.

Our network comprises an area of 1 km^2 , with 4 bidirectional roads and 4 junctions, each one of them having an AP, as represented in Figure 3. We used 100 vehicles to simulate a situation of road traffic with average intensity. Their initial location represents a situation of an unevenly distribution in the map, with a region with high density of vehicles (left side) and another one with low density (right side).

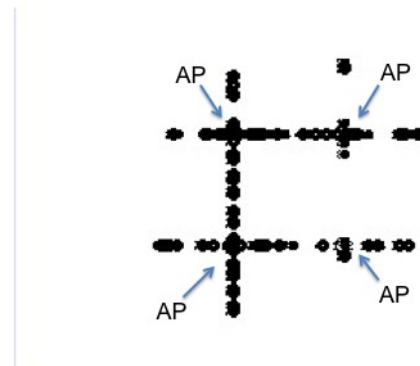


Fig. 3. Network Topology

The 802.11b protocol was used for the MAC layer of the vehicles. As we want to compare our extensions with the standard version of the protocol, every test was repeated with a different MAC in the AP. Thus, we have:

- 802.11 - use of the standard 802.11;
- CW - use of the extension that stalls the AP's CW;
- SIFS - use of the extension that changes the AP's IFS.

- SIFS+CW - use of both extensions.

The Two Ray Ground Propagation model was used and had a receiving range of 100 meters. Although this model does not take into account propagation interference caused by buildings, this was the most adequate model that we found in ns-2 version 34. Although physical interference is not used, it is simulated once in junctions a node has to send to the AP. Hence the communication would not transverse the corner.

In order to emphasize the impact of our modifications, most of the traffic streams are generated in the neighborhood of AP1 so that the AP is used as an hop in the forwarding process of every packet. Both CBR and TCP traffic were used in the simulations. For CBR traffic Packet Delivery Ratio (PDR) was used as metrics, which is measured as defined in Eq. 1

$$PDR = \text{Received_Pkts}/\text{Transmitted_Pkts}[\%] \quad (1)$$

For TCP traffic Throughput (TP) was used as metrics, which is measured as defined in Eq. 2.

$$TP = \text{Received_kbits}/\text{Session_duration}[\text{kb/s}] \quad (2)$$

For each one of the tests proposed, 30 simulation runs were executed and a confidence interval of 95% was achieved.

B. Simulation results - CBR traffic

The performance of our network when using CBR traffic was evaluated considering three different aspects: packet size, packet rate and number of connections. In each one of the tests, the mentioned parameter changes while the other are fixed.

The first set of simulations were used to select the most adequate packet size. Five CBR connections were used, each one of them generating traffic at a rate of 50 kb/s; the packet size varies between 128 and 1024 Bytes.

In Figure 4 is represented the graphic of the PDR.

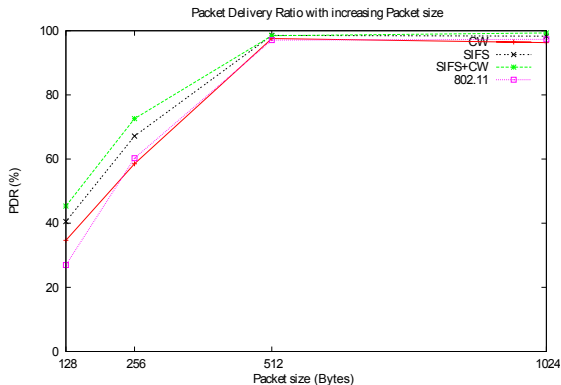


Fig. 4. CBR traffic with different packet sizes

As can be observed, the PDR increases with the packet size since the overhead is reduced, being all the MAC solutions almost similar for packets bigger than 512 Bytes.

With bigger overheads (smaller packets), the SIFS+CW solution offers the best performance, being the PDR almost 50% better than the PDR achieved by the standard MAC, if the packet size is 128 Bytes. This is justified by the fact that small packets do not need a long time to be send: before the node has another packet to transmit the AP probably already finished sending the previous packet and thus collisions are less probable to happen.

In the second test five CBR connections with a packet size of 512 Bytes were used with a packet rate varying between 2 and 20 Pkts/s, e.g. between 8 and 80 kbps.

In Figure 5 it is seen the PDR variations, showing that PDR increases when network load decreases. The maximum rate that allows a PDR of almost 100% is shared by all MAC mechanisms, being about 10 pkts/s. Major differences are foreseen in the various MAC algorithms when the packet rate is higher than this value. Again, SIFS+CW presents the best performance, by achieving a PDR near 60%, which is quite good when compared to the 40% achieved by the standard 802.11.

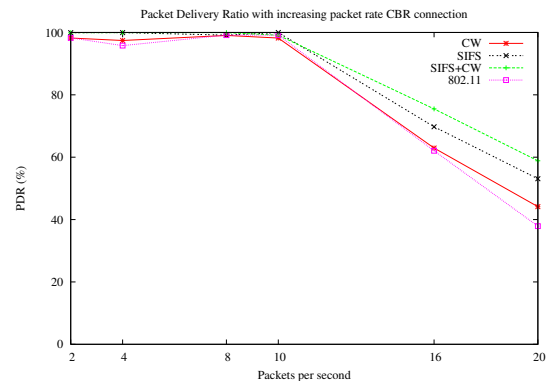


Fig. 5. CBR traffic with different packets sizes

The last set of simulations were used to evaluate the performance of CBR traffic, under the occurrence of different network load conditions. Packets of 512 bytes were generate at a rate 10 pkts/s, with a number of connections varying between 5 and 20. Figure 6 shows the PDR results of these tests.

As it can be observed, PDR decreases when the number of simultaneous connections increases. Enhanced MAC versions have better results, but with 10 connections PDR is always small than 60%, even if SIFS+CW enhanced MAC is used.

C. Simulation results - TCP traffic

The performance of our network when using TCP traffic was evaluated considering two different aspects: packet size and number of connections, as the rate is automatically adjusted by TCP protocol according to the traffic conditions. In each one of the tests, the mentioned parameter changes while the other is fixed.

TCP was parameterised using a similar approach. Five TCP sessions were used with a packet size varying between 128 and 1440 Bytes.

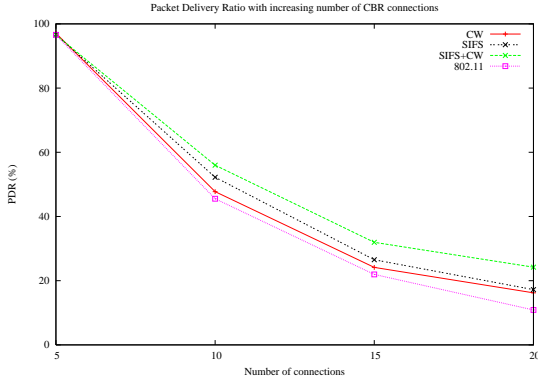


Fig. 6. CBR traffic with different number of sessions

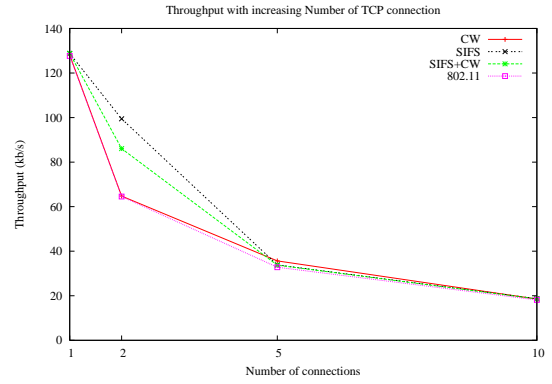


Fig. 8. TCP traffic with different number of sessions

In Figure 7 is represented the graphic of the PDR. While significant differences have been observed when CBR traffic is used, when TCP traffic is used the different MAC mechanisms present a similar behavior. This happens due to the congestion control mechanism of TCP that are activated in case of loss events.

number of CBR connections increases. This can be easily explained by the fact that TCP is able to regulate the amount of generate traffic, meaning that an higher number of TCP connections does not represent an higher traffic volume. Thus, the modifications on MAC layer are more relevant when the predominant traffic is CBR due to the higher and uncontrollable network load.

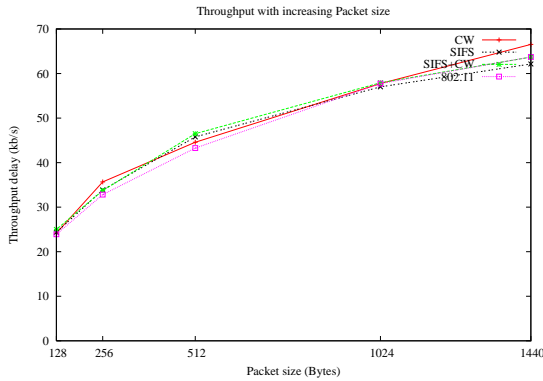


Fig. 7. TCP traffic with different packets sizes

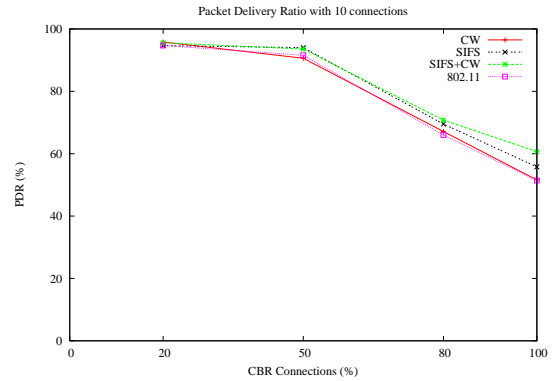


Fig. 9. Impact of TCP in CBR traffic

Tests with different number of TCP connections were made (see Figure 8) and the results were also very similar between the different mechanisms.

The impact of CBR on TCP traffic is represented in Figure 10. As it can be seen, the introduction of CBR traffic has a strong impact on the performance of TCP, being the differences between the proposed MAC extensions and the standard MAC much more relevant than those achieved when TCP flows alone in the network.

D. Simulation results - CBR and TCP traffic

According to the results previously described, using the SIFS+CW mechanism seems to be the most adequate solution, as it assures better performance for both CBR and TCP traffic, even when the network load volume increases. In light load conditions, it offers a similar level of service than the one that is provided by the other solutions.

The final set of tests represents a more realistic situation in which both types of traffic coexists, by varying the percentage of traffic of each type. We used the most adequate parameters for each one of them obtained in previous simulations. These parameters can be seen in table I.

TABLE I
CBR AND TCP TRAFFIC PARAMETRISATION

Traffic type	CBR	TCP
Packet size [Bytes]	512	512
Packet rate [pkt/s]	10	-n.a.
Number of connections	[0,2,5,8,10]	[10,8,5,2,0]

V. CONCLUSIONS

As it is shown in Figure 9 the PDR decreases when the

In this paper was introduced an all-IP VANET architecture in which both V2V and R2V communications are used. The architecture uses a modified version of GPSR in order to make the traffic pass through the AP to solve the urban obstacles propagation problem. Two modifications

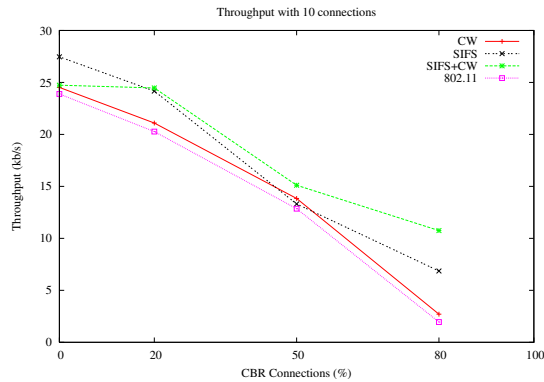


Fig. 10. Impact of CBR in TCP traffic

were proposed to the AP's MAC layer that can either be used alone or together.

The results show that with CBR traffic in high network loads a better performance can be achieved specially if both modifications are used. With TCP traffic the various mechanisms have similar performance, being that the modification make slight improvement.

However, in a more realistic scenario where both types of traffic are mixed our proposed extensions outperformed the standard MAC specially under heavy load conditions. The used of SIFS+CW mechanism demonstrates that it is better than the others due to the higher priority given to the APs in the medium access.

In the future, we want to evaluate the performance of our algorithm in different networks, and different road traffic conditions (mobility). A more realistic traffic scenario, representing a mix of traffic types must also be evaluated.

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