Using a symmetric game based in volunteer's dilemma to improve Vanets multihop broadcast communication

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***Abstract*—Many applications in VANETs use broadcast communications to disseminate information or keep proper functionality in a network. When the broadcast is multi-hop, it tends to cause unnecessary resource consumption due to the excessive redundant packets on the network, this is known as the broadcast storm problem. Recently, the broadcast storm problem has gained attention due to the impact on VANETs. Many studies emphasize the importance of the forwarding area as a factor for choosing forwarder vehicles. But as important as the use of the area is knowing how many candidates there are to forward a broadcast message. This paper proposes a technique to mitigate that problem through a game theory mechanism: "the volunteer's dilemma". With this mechanism, the probability of a vehicle forwarding a message is computed, taking into account the cost and the benefit of message propagation. The mechanism's behavior was evaluated by simulations using NS-2. Results showed that when comparing it to a protocol that uses only the area which will be covered as factor for calculating the forwarding probability, packet loss ratio was reduced, as well as latency.**

I. INTRODUCTION

Intelligent transport systems (ITS) focus on reducing the number of driver errors. Every vehicle becomes a processing device which analyzes the collected data to build information which is useful to a neighborhood; and the nodes use a communication system to exchange data in a fully mobile dynamic environment.

The most suitable architecture of an ITS is an Ad-Hoc network. Ad-Hoc networks are built on demand, with no central coordination; therefore, the focus of ITS researches leans towards adapting these networks to a vehicular environment, and hence creating the VANETs. This adjustment is necessary because there are different features in the vehicular environment [1], [2], [3], then the common purpose of Ad-Hoc networks, such as: highly dynamic topology, sufficient energy and processing capacity, mobility model predictability, and communications with a high amount of broadcast traffic.

This last feature mentioned, which shows the high amount of broadcast traffic, arises in VANETs applications, classified by Hartenstein [4] as: safe, efficient, infotainment – relying specifically on data of general interest. These networks require a high level of reliability on data delivery, data penetration – which is the amount of data receivers, and a limited time for the delivery of data, a feature which does not exist on regular mobile Ad-Hoc networks.

As highlighted on Sivakumar [5], blind flooding, which is the simplest way of forwarding broadcast, conflicts with the network needs, since it overloads the network with a high number of forwarded messages which is countless times greater than the number of available nodes in the network. It also generates some interference due to the environment which is not reserved for these transmissions – RTS/CTS agreements – making them collide.

The behavior mentioned above is well-known as broadcast storm problem. VANETs are self-organized and they have distributed coordination, thus all the network nodes are responsible for tackling the problem. The introduction of an intelligent mechanism of distributed control which may coordinate the communication between nodes becomes even more necessary with the network demographic boom.

In this paper, the Volunteers Dilemma Game modeled by Diekmann [6] is evaluated as a mechanism to quench the broadcast storm problem. The probability of a broadcast message forward, being made by a vehicle, is calculated using the number of candidate vehicles to forward the message, i.e., the number of vehicles that are listening to the transmission, as well as the cost/benefit relation to forward the message by the vehicle, which is obtained from the distance between the candidate node and the node that is transmitting the message.

The other part of the article is organized as follows. Section 2 gives a detailed description of the problem. Section 3 discusses the related studies. Section 4 focuses on presenting the usefulness of the Volunteers Dilemma as a mechanism to quench the broadcast storm in VANETs. In section 5, we analyze the experimental results. Finally, section 6 presents the conclusions and future works that might be performed.

II. BROADCAST STORM PROBLEM

VANETs need to disseminate data, which means, in broadcasting terms, to spread data targeted to a set of vehicles without knowing how they will absorb this data. The information can be analyzed, ignored, or even corrupted.

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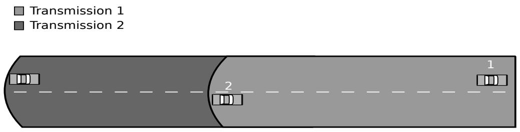
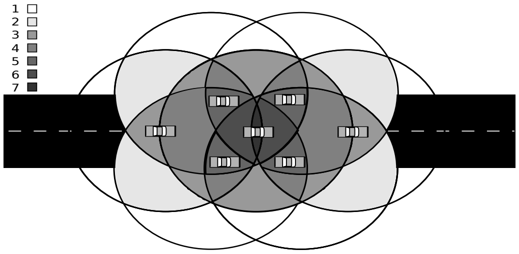
On the WAVE standard [7], broadcast message forwarding at the MAC layer passes through a process similar to the one specified as Enhanced Distributed Channel Access (EDCA) [8] to the WLANs. It is also important to highlight the constant presence of hidden terminals in broadcast communications, since the channel reservation mechanism to treat this problem is not present during the communication. Having a great amount of vehicles interested in one transmission increases the amount of collisions in the wireless environment.

Lim [10] was not only able to present the magnitude of collisions in a mobile Ad-Hoc network, but also verified that besides the flaw of the 802.11 broadcast mode, there is another severe flaw in the way that broadcast messages are forwarded by the network. Initially, every message was forwarded if the nodes listened to it for the first time, otherwise it would be discarded. This forwarding mode is known as Blind Flooding, because it blindly forwards its received messages. Figures 1(a) and 1(b) illustrate a message being forwarded in the network under the Blind Flooding mechanism, showing both a low and high density of vehicles.



a) Low Density



b) High Density

Fig. 1. Redundancy in the blind flooding operation.

In a low-density scenario, when two nodes are mutually out of range, a single forward is enough for the communication to happen correctly. However, with the density growth, some unnecessary communications happen, which means more forwarding in the environment, creating redundant traffic in the network as well as little gain in terms of new message receptor nodes.

In VANETs, the broadcast storm problem was studied by Wisitpongphan [9]. It was verified that there was a growth in the number of hops taken by a message to reach its destination, a growth in the delay, and a significant increase in the number of lost packets in a high density environment. In analyzing these issues, it was concluded that the biggest issue is the great number of packets lost, since the car driver cannot notice the delay during safety applications.

III. RELATED WORKS

Ad Hoc networks literature provides a great deal of studies that focus on solving the broadcast storm problem. Lim [10] proved that the optimal broadcasting solution is a NP-COMPLETE. Therefore, the known solutions are only approximations of the optimal one. Camp [11] classified them as: probabilistic, area-based and neighborhood-based.

Neighborhood-based protocols – as proposed by Amoroso [12] – control the broadcast storm by using data exchange through messages which are used in the forwarding decision.

Area-based protocols give priority to message forwarding that will cover the largest new area, area which has not been covered by the message forwarding yet. Wisitpongphan [9] proposed this type of protocol.

The probabilistic technique of reducing the broadcast storm allows message forwarding according to an adjustable probability concerning some data from the network topology, as proposed by Ferrari [13].

Among all the mechanisms proposed in literature to minimize the problem, the most similar to the one presented in this work is an algorithm shown by Wisitpongphan [9]. The key idea is to differentiate the forwarding of each possible transmitter vehicle – vehicles within the transmission range (R) – based on the distance (D_{ij}) between the forwarding candidate vehicle (vehicle *j*) and the one sending the message (vehicle *i*). A mix of area-based with a probabilistic mechanism was suggested, the Weighted-P. Algorithm 1 shows its basic operation.

```
Input: the received packet
if packet with ID was previously received from a sender i then
    Discard packet;
else
    $p_{ij} \leftarrow \frac{D_{ij}}{R}$;
    $rng \leftarrow uniform(0,1)$;
    if $rng \leq p_{ij}$ then
        forward packet;
    end
end
```

Algorithm 1: Weighted-p Forwarding

The probability of a node forwarding a message is proportional to the distance between the transmitter vehicle and the possible vehicle to forward it. A given vehicle (*j*) will forward a message with an *ID* identifier according to a p_{ij} probability. If the message is received for the first time from vehicle (*i*), it is accepted, otherwise it will be discarded. For a time $(WAIT\_TIME)$, after receiving the first message with the ID identifier, new ID messages, which may arrive to be forwarded, will be verified and p_{ij} will be calculated for each of them, the one with smallest probability value will be selected. If the vehicle decides not to forward the message, it will keep it stored for a time $(WAIT\_TIME + \delta\text{ms})$, where δ is the message transmission and propagation time. After this time is over, and in case it did not listen to any forwarding of the *ID* message, the vehicle will forward the message.

Despite the advantages of Weighted-P, it is a static protocol for the scenario around it because it does not highlight the fact that vehicular density interferes in the problem. It uses only the distance between vehicles as a parameter to determine the probability. This protocol despises the fact that if the number of vehicles increases, more forwarding control must be done to prevent possible jeopardizing of network operation.

IV. USING VOLUNTEER'S DILEMMA IN BROADCAST FORWARDING

Interactions between separate entities are a common situation in communications (see routing protocols), where there is an intense exchange of messages to enable these entities to properly perform the task for which they were designed. One agents behavior affects positively or negatively another agents behavior, which is called interdependency. Situations in which there is interdependence are known as strategic scenarios. In these scenarios, an agent chooses the best strategy to respond to an expected behavior from the other agents involved. Due to the great importance in that agent strategy, systematic studies were developed and generated a strategic interaction theory called the game theory, deeply studied by Fundenberg and Tirole [14].

Broadcast communications is an interaction between different vehicles in a network that occurs in order to run a task correctly so that the network attends its purpose. The behavior of the message receiver vehicle affects positively or negatively the behavior of other vehicles in a VANET, depending on whether there was a choice of forwarding the message or not.

The goal of all mitigation broadcast storm mechanisms is to select from the vehicles that have listened to the message, those which will forward it with the lowest cost for the network. When that happens, even the vehicles which have not forwarded the message will benefit by a forwarding performed by another vehicle. This behavior, in which common good is produced by a player, was modeled by the volunteer's dilemma [6]. Adapting it to the broadcast storm problem in MANETs, Naserian [15] called this the forwarding dilemma game, it is the decision between forwarding a message and generating a benefit; or not forwarding the message to enjoy the benefit to be generated. In this paper a new approach for VANETs based on the later ideas is proposed.

Representing broadcast forwarding by the game $G = \{N, (S_{p_i})(i \in N), (U_{p_i})(i \in N)\}$ where N is the number of participating vehicles, S_{p_i} is the strategy set, and U_{p_i} is a utility function for a p_i player. A player p_i strategy S_{p_i} is $S_{p_i} = \{0, 1\}$, where $s_{p_i} = 1$ implies message forwarding and $s_{p_i} = 0$ no message forwarding. A p_i node receives the payoff U_{p_i} after the strategy choice. The game is played whenever a vehicle receives a broadcast message that must be forwarded. The number of players is the amount of vehicles that receives the message. A cost is associated to the message forwarding. Because of that cost each participant in the game expects another one to produce the message forwarding. The vehicle p_i that forwards the message will have payoff $U_{p_i} = B - C$, in which B is the benefit value generated and C is the benefit production cost. The other vehicles, that shall use the good produced, will have payoff $U_{p_{-i}} = B$. The game in its normal form is represented in the matrix below.

P_i/P_{-i}	ALL QUIET	AT LEAST ONE FORWARD
QUIET	0	B
FORWARD	$B - C$	$B - C$

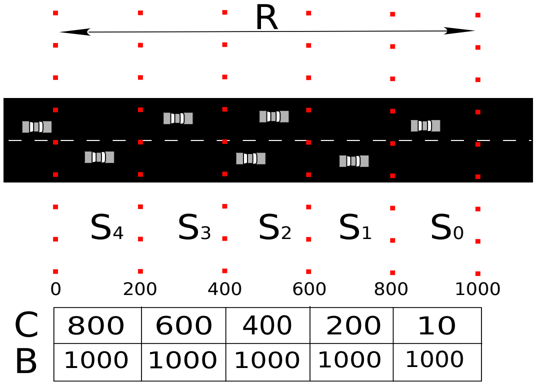
TABLE I
THE GAME IN THE NORMAL FORM.

It is assumed that in the game $B > C$, in order that no player is prevented from participating. Diekmann [6] proved that the game goes into Nash equilibrium according to the symmetric mixed strategy, in which each player may volunteer, representing the forwarding, with probability p equal to equation 1 and the benefit – the message being forwarded by some player, will be produced according to a probability p' by the equation 2:

$$p = 1 - (\frac{C}{B})^{\frac{1}{N-1}} \tag{1}$$

$$p' = 1 - (\frac{C}{B})^{\frac{N}{N-1}} \tag{2}$$

Unlike Naserian – which uses a cost equal to 1 and a benefit in which $3 \leq log(B) \leq 6$ – in VANETs the cost and the benefit were obtained from the area associated to the forwarding. The forwarding dilemma is a symmetrical game, so all players need an identical cost-benefit ratio $(\frac{C}{B})$. For this, the sender vehicle transmission range was divided into a number of sectors $(NSec)$, from the farthest sector (0) to the closest one $(NSec - 1)$. Each sector delimits an area of size (A_{sec}) where the cost related to forwarding is less than the cost of an immediately adjacent area closer to the transmitter vehicle. So, the farther the forwarding contender vehicle, the greater the payoff routing is. With the cost being associated to the sector, all vehicles within the same sector may have the same cost-benefit ratio. Figure 2 shows a vehicle transmission range divided into 5 sectors.



C	800	600	400	200	10
B	1000	1000	1000	1000	1000

Fig. 2. Transmission Range Sectorization.

Throughout the forwarding, the benefit will be the transmission range R. The cost is the minimal redundant distance related to a sector, i.e., the radius R minus the distance from the farthest edge in the sector from the message transmitter $(R - (R - (A_{sec} \times SectorNumber)))$. A vehicle will know which sector is associated using the distance between itself and the message transmitter. With its own position obtained from the GPS and the transmitter vehicle position contained in the header of the incoming message, it is possible to calculate the distance between them and then get the sector number. In order to not have a null cost in the farthest sector - sector 0 - because C would be $R - R$, the value 10 was adopted. The figure below represents the probability values for generating a forwarding within each sector using the equation 2.

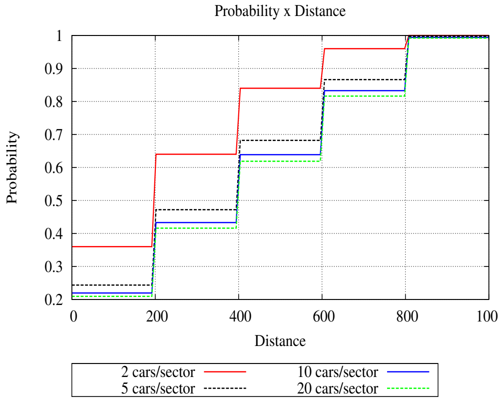


Fig. 3. Probability of a forwarding happen in a sector.

Therefore, the characteristic to prioritize according to the area to be covered by a new forwarding was kept in the forwarding dilemma game adapted to VANETs. In addition, the figure below shows that the probability of a vehicle forwarding a message is completely related to the amount of vehicles within a sector. This data can be obtained using a mobility management mechanism such as the one proposed by Jérôme Härri [18]. As the mechanism can be used to optimize the operation of other network services, the cost of its adoption is diluted. According to equation 1, this probability decreases when the number of neighbors in a sector increases.

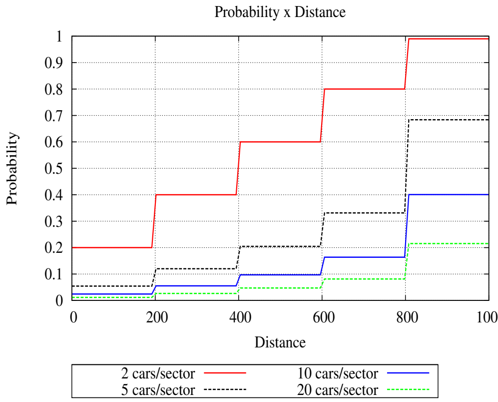


Fig. 4. The probability of a message being forwarded by a vehicle.

Algorithm 2 shows the game operation.

```
Input: the received packet
if packet with ID was previously received then
    Discard packet;
else
    $p \leftarrow 1 - (\frac{C}{G})^{(\frac{1}{N-1})}$;
    $rng \leftarrow uniform(0, 1)$;
    if $rng \leq p$ then
        forward packet;
    else
        wait for $WAIT\_TIME$;
        if packet was not forwarded by another vehicle
        then
            forward packet;
        end
    end
end
```

Algorithm 2: Adapted forwarding dilemma game.

$WAIT\_TIME$ is calculated according to the following formula:

$$WAIT\_TIME = 0.005 + (SLOT\_TIME \times (R - D)) \quad (3)$$

Where $SLOT\_TIME$ represents a time slot of the WAVE, R represents the transmission range and D the distance between the transmitter and the forwarding candidate vehicle.

V. RESULTS

The game behavior was evaluated in a road scenario where a static node spreads broadcast messages that propagate up to a static node 10km away from it. For the possibility of a broadcast message to reach the latter static node, a VANET is required to connect these two extremes.

The vehicle flow in VANET was originated according to Poisson Point Process, in which the vehicle locations are set randomly according to a density β (vehicles per meter), where a probability $p(i, l)$ of finding i vehicles in a space l is given by the equation below.

$$p(i, l) = \frac{(\beta l)^i e^{-\beta l}}{i!} \quad (4)$$

Four different densities were considered in the generation of scenarios: light (10 cars per kilometer), moderated (25 cars per kilometer), heavy (50 cars per kilometer) and jam (100 cars per Kilometer). The Simulator NS-2 [16] was used to evaluate the game performance. In the evaluated scenarios, a vehicle sends a 1024 byte packet every 0.1 second. Every vehicle had a 1 km communication range and the signal fades according to the Nakagami propagation model. The experiments had a duration of 500 seconds and were run 100 times; the confidence interval of 95% was calculated.

Link Load – The amount of packets per time unit that each vehicle in the network heard on average during the simulation, shows the useful throughput in the network. The higher the link load, the greater the redundant traffic. Both Weighted-P, and the forwarding dilemma game reduced the link load on the network. They had quite similar performances, differing only in light traffic scenario, in which the link load game was higher due to the forwarding probability increase because of a low amount of neighbors in the sector.

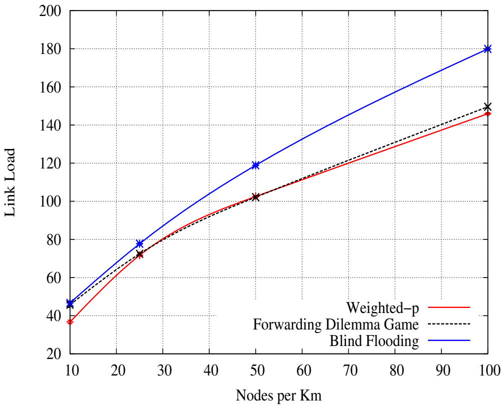


Fig. 5. Link Load

Packet Penetration Rate – It is also important to know whether the mitigation problem technique interferes in the network connectivity. Some parts in the network may be uninformed due to the low probability and no forwarding message. Weighted-P and forwarding dilemma game techniques obtained an amount of vehicles that has heard the message similar to the blind flooding. Therefore, the probability did not influence negatively on the network packet penetration.

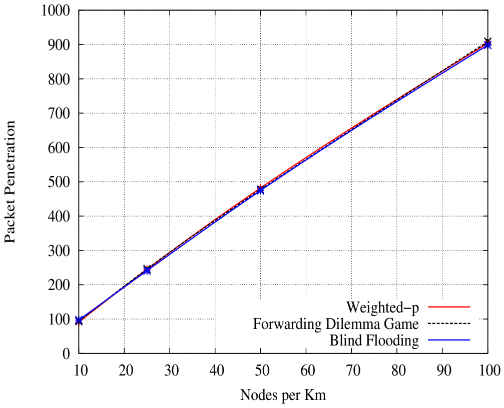


Fig. 6. Packet Penetration Rate

Latency – the end-to-end delay in the Weighted-P mechanism is significantly greater than in the game, especially in a light traffic scenario, where the latter has a similar performance to blind flooding. The game can have a performance close to the blind flooding by not adding $WAIT\_TIME$ to the forwarding, as the Weighted-P does. This has proved to have a significant impact on latency observed in a vehicle 10km distant from the initial message transmitter.

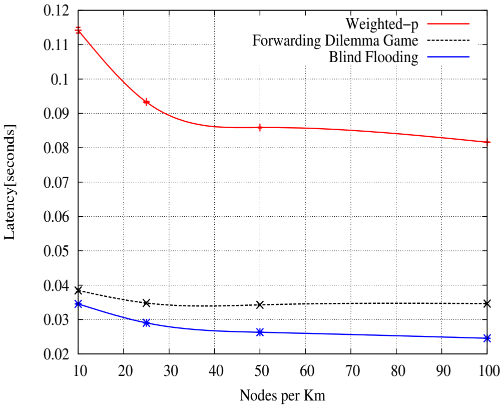


Fig. 7. Latency

Packet Loss Ratio – Packet loss on the network can cause serious problems for a running application on the network. In Weighted-p, 60% of the messages transmitted to a vehicle on the network were lost in a light traffic scenario, while in the same scenario the game reduced this percentage to 40%. The percentage of loss increases with the amount of vehicles, even so the game got a smaller percentage in the remaining scenarios, the improvement being reduced to 8% in a vehicular traffic jam.

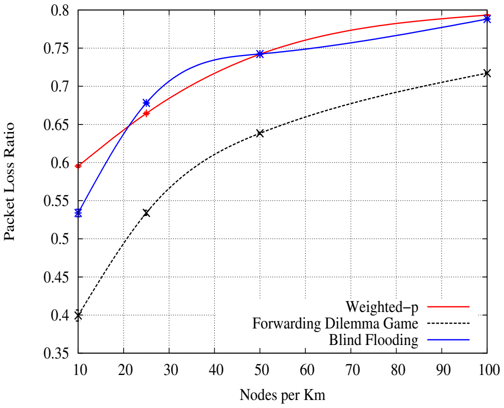


Fig. 8. Packet Loss Ratio

Hops – The amount of hops in the probabilistic mechanisms decreased when compared to the amount of hops in blind flooding. Therefore, they privilege the forwarding vehicle farthest from the message transmitter. However, the game always had more hops than the Weighted-P. This arises from the fact that the wait time of Weighted-p ($WAIT\_TIME$) work as a forwarding inhibitor that could be performed by a farther vehicle. If a forwarding candidate vehicle receives a message from a distant vehicle, and within the $WAIT\_TIME$ range it receives the same message from a closer vehicle this time, the forwarding candidate vehicle will recalculate the routing probability and reduce it, thereby giving priority to those which are more distant. For those in the game, that do not have any wait time, there is no recalculation of forwarding probability, thus generating a greater quantity of hops.

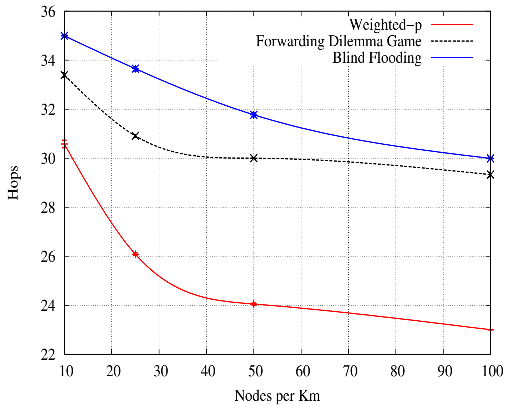


Fig. 9. Hops

VI. CONCLUSION

In this paper we propose the use of the volunteers dilemma game as a mechanism for mitigating the broadcast storm in VANETs. The idea is to use the common good production probability as the message forwarding probability. For this, information such as the area benefited by the forwarding and vehicular density were used as parameters for calculating the probability.

Vehicular density proved to be an important parameter for message forwarding. Its use along with the forwarding area, described in terms of cost benefit, was beneficial to the network. The results showed that the game significantly reduced the packet loss ratio on the network, because the probability, unlike Weighted-p, adapted to the surrounding area. The probability did not influence negatively in the message network penetration, and the probabilistic mechanisms kept the same blind flooding penetration.

The results showed that another parameter which greatly influenced the results was the wait time before forwarding a message. The $WAIT\_TIME$, in Weighted-p, was an important factor to reduce the number of hops required to reach a distant vehicle when Weighted-p is compared with the game. However, in terms of latency, $WAIT\_TIME$ absence in the game reduced significantly the end-to-end delay.

Thus, in future works, it is important to study $WAIT\_TIME$, so that a balance between latency and quantity of hops can be reached. In the game, despite the message loss reduction in the network, it may be interesting to study the forwarding cost-benefit ratio ($\frac{C}{B}$), so that this study could influence in the game link load reduction, which remained similar to Weighted-p.

The game used here is symmetrical. Wessie [17] considered the situation where players will produce a common good under different costs, featuring an asymmetry. In the future, this asymmetry will be considered for the forwarding cost calculation.

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