Data Dissemination in Vehicular Environments

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Design and performance evaluation of smart dissemination of emergence messages in vehicular ad-hoc networks

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Part IV
Annexes

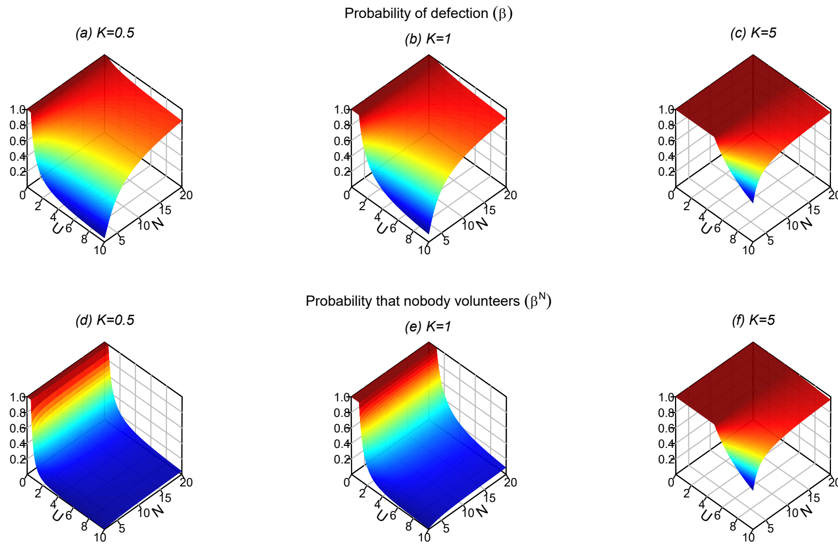
Appendix A
Volunteer's dilemma game

The mixed-strategy equilibrium in the Volunteers Dilemma Game can be found by equating the payoffs of the two pure strategies, which gives:

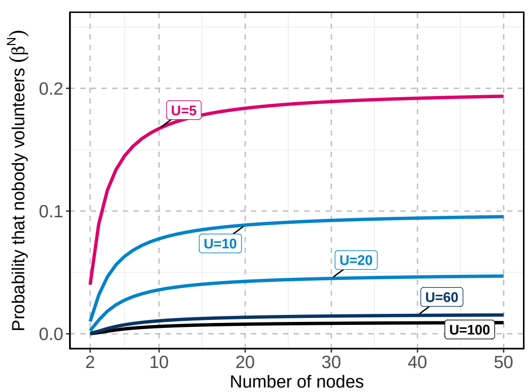
$$\beta_{eq} = \left(\frac{K}{U}\right)^{\frac{1}{N-1}} \tag{A.1}$$

Figure A.1a models the behavior of Equation (A.1) for different values of utility U, number of nodes N and cost of cooperation K. The main findings are analyzed below. First, the probability of defection (β_{eq}) increases with K (*i.e.*, for an expensive cooperation) and decreases with U (*i.e.*, it is worth collaborating). Second, the probability of defection increases with the number of neighbours. For instance, with $K = 0.5$ and $U = 10$, $\beta_{eq} = 0.05$ with $N = 2$; $\beta_{eq} = 0.72$ with N=10; $\beta_{eq} = 0.97$ with N=100. Next, the probability that nobody volunteers (β_{eq}^N) also increases with N and decreases with the utility U. Since $\beta_{eq} = \left(\frac{K}{U}\right)^{\frac{1}{N-1}}$ then $(\beta_{eq})^{N-1} = \frac{K}{U}$, and $(\beta_{eq})^N = \beta_{eq} \cdot \left(\frac{K}{U}\right)$, which is increasing in N (because β_{eq} is increasing in N). This can be clearly seen in Figure A.1b for example when $U = 5$ and $K = 1$. For $N = 2$ the probability that nobody volunteers is $(\beta_{eq})^2 = 0.04$, with $N = 10$, the probability rises to $(\beta_{eq})^{10} = 0.17$ and with $N = 50$ to $(\beta_{eq})^{50} = 0.19$. Therefore, the probability that someone will volunteer decreases with the number of neighbours as it is depicted in Figure A.1b.

This version of the game is referred to as symmetric volunteer's dilemma. Conversely, Diekmann presented an analysis of an asymmetric volunteer's dilemma game [27]. In that version of the game, the author introduced an unequal distribution of cost of volunteering K_i and benefit U_i earned when at least one player i volunteers in a group of size N players. If we let strategy D_i be played with probability β_i, the expected utility of player i can be expressed as follows:



(a) The defection probability β *(a-c)* and the probability that nobody volunteers β^N *(d-f)* at equilibrium as a function of the group-size N and the utility U for different costs of cooperation (K). The color graph represents probabilities of the player ranging from zero to one.



(b) Probability that nobody volunteers β^N at equilibrium as a function of the group-size N for a cost of cooperating $K = 1$ and different utility values U.

Fig. A.1: Mixed-strategy equilibrium in the volunteers' dilemma game.

$$E_i = \overbrace{\beta_i \cdot U_i \cdot \left(1 - \prod_{j \neq i}^{N} \beta_j\right)}^{\textbf{Defect (D)}} + \underbrace{(1 - \beta_i) \cdot (U_i - K_i)}_{\textbf{Collaborate (C)}} \tag{A.2}$$

where β_i is the player i's probability of defection, U_i is the benefit earned by that player when at least one player volunteers, β_j is the average defection probability of all the other players ($j \neq i$), and K_i is the cost of volunteering for that player i.

The best response function for player i can be obtained by maximizing Equation (A.2):

$$\frac{\partial E_i}{\partial \beta_i} = U_i \cdot \left(1 - \prod_{j \neq i}^{N} \beta_j\right) - (U_i - K_i) \tag{A.3}$$

Partially differentiating with respect to β_i yields

$$\frac{\partial E_i}{\partial \beta_i} = U_i - U_i \cdot \prod_{j \neq i}^{N} \beta_j - U_i + K_i \tag{A.4}$$

The following system of N equations results if the derivatives are set equal to zero:

$$\frac{K_i}{U_i} = \prod_{j \neq i}^{N} \beta_j, \quad i = 1, 2, ..., N \tag{A.5}$$

$$\begin{cases} \dfrac{K_1}{U_1} = \beta_2 \cdot \beta_3 \cdot \beta_4 \ldots \beta_N \\ \dfrac{K_2}{U_2} = \beta_1 \cdot \beta_3 \cdot \beta_4 \ldots \beta_N \\ \dfrac{K_3}{U_3} = \beta_1 \cdot \beta_2 \cdot \beta_4 \ldots \beta_N \\ \quad \vdots \\ \dfrac{K_N}{U_N} = \beta_1 \cdot \beta_2 \cdot \beta_3 \ldots \beta_{N-1} \end{cases} \tag{A.6}$$

Taking Equation (A.5) and rearranging yields the following equilibrium solution:

$$\beta_i \cdot \frac{K_i}{U_i} = \beta_i \cdot \prod_{j \neq i}^{N} \beta_j$$

$$\beta_i = \frac{U_i}{K_i} \cdot \prod_{j=1}^{N} \beta_j \tag{A.7}$$

Multiplying both sides of the system of equations represented in Equation (A.6) and clearing β_j, we obtain:

$$\frac{K_1}{U_1} \cdot \frac{K_2}{U_2} \cdot \frac{K_3}{U_3} \dots \frac{K_N}{U_N} = \beta_1^{N-1} \cdot \beta_2^{N-1} \cdot \beta_3^{N-1} \cdot \beta_4^{N-1} \dots \beta_N^{N-1}$$

$$\prod_{j=1}^{N} \frac{K_j}{U_j} = \left(\prod_{j=1}^{N} \beta_j \right)^{N-1}$$

$$\left(\prod_{j=1}^{N} \frac{K_j}{U_j} \right)^{\frac{1}{N-1}} = \prod_{j=1}^{N} \beta_j \tag{A.8}$$

Replacing Equation (A.8) in (A.7), we get the solution of the best response for player i:

$$\beta_i^* = \frac{U_i}{K_i} \cdot \left(\prod_{j=1}^{N} \frac{K_j}{U_j} \right)^{\frac{1}{N-1}} \tag{A.9}$$

Appendix B
Forwarding game

Unlike the volunteer's dilemma, in the forwarding game the outcome is the probability that each node forwards the message. Based on [62], we identify the availability of a node a_i and the strategy of its neighbouring nodes S_i as main metrics that allow node i to select a strategy S_i that maximizes its utility U_i.

The designed utility function is defined as:

$$U_i(S_i, a_i, Q_i) = \frac{a_i \cdot S_i}{Q_i} \cdot exp\left(\frac{-S_i^2}{2 \cdot k \cdot a_i^n \cdot Q_i^m}\right) \tag{B.1}$$

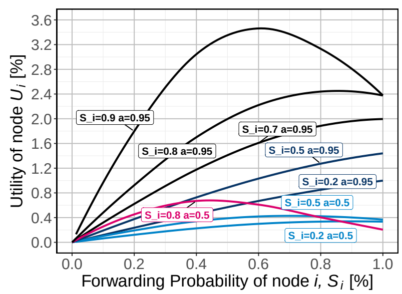
where k, m and n are constant values, a_i is the availability of node i, and Q_i is the neighbour action reflection.

As our main goal is to mitigate the broadcast storm problem and therefore improve the overall performance of the network by eliminating redundant broadcast, the utility function U_i of the players have the following features:

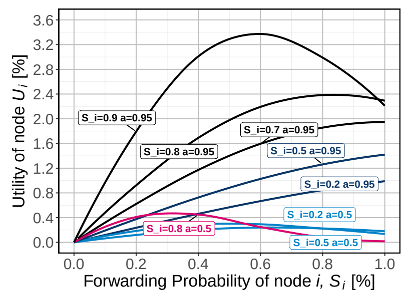
1. When node i computes a high availability ($a_i \to 1$), it should increase its forwarding probability S_i.
2. When node i computes a low availability ($a_i \to 0$), it should decrease its forwarding probability S_i.
3. When node i estimates that its neighbouring nodes may not forward the packet with high probability ($S\_i \to 0$), it should increase its forwarding probability S_i.
4. When node i estimates that its neighbouring nodes are forwarding the packet with high probability ($S\_i \to 1$), it should select a lower forwarding probability S_i to save its resources.

To find the optimum values for k, m and n, Figure B.1 shows our evaluation of the best response function of Equation (B.1) with different values of k, m, n, a_i and S_i. As it can be seen in Figures B.1c and B.1d, the designed utility function shows optimal results with values of $k = 4$ and $m = 2$ while parameter n can be any value from 2 to 4. In our simulation results showed that $k = 4$, $n = 3$ and $m = 2$ would provide optimum results.

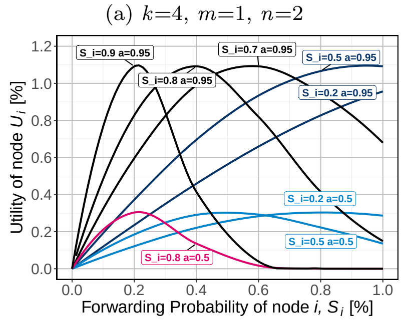
To verify that the utility function fulfills the features detailed above, Figure B.1d shows the utility of a node U_i vs. its forwarding probability S_i for different values of a_i and S_i. When the availability of node i is high (*e.g.*, $a_i = 0.95$), the forwarding probability of a node increases (*e.g.*, $S_i = 1$) when the node finds out that the other neighbours may not forward the message (*e.g.*, $S\_i = 0.2$). Likewise, S_i decreases (*e.g.*, $S_i = 0.2$) when the node estimates that the other neighbours may forward the message (*e.g.*, $S\_i = 0.9$). This induces the node to reduce the forwarding probability if other neigh-



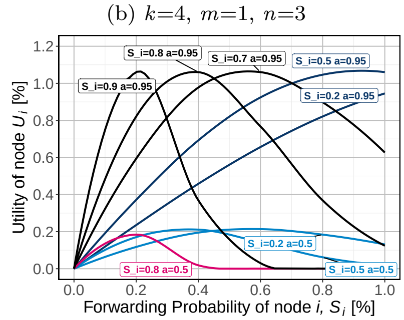
(a) k=4, m=1, n=2



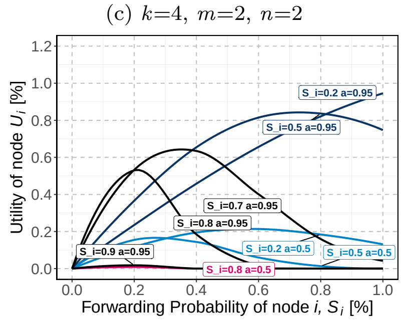
(b) k=4, m=1, n=3



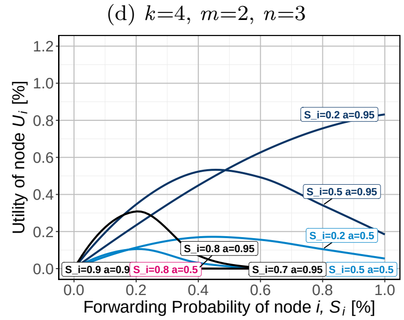
(c) k=4, m=2, n=2



(d) k=4, m=2, n=3



(e) k=5, m=3, n=3



(f) k=4, m=4, n=3

Fig. B.1: Utility of node i *vs.* its forwarding probability, for different values k, m and n.

bours have shown a high participation level in forwarding messages (*e.g.*, $S\_i = 0.8$). The same behavior occurs when the availability of node i decreases (*e.g.*, $a_i = 0.5$) with low utility values. Note how Q_i generates a balance between node i and its neighbours for forwarding messages. This controls overhead by eliminating redundant broadcasts. Concluding, Utility presents one maximum point that is dependent of the forwarding probability.

Setting the derivative of Equation (B.1) equal to zero, we get an expression that allows us to calculate the maximum utility of node i as a function of parameters a_i and Q_i:

$$\begin{aligned} \frac{\partial U_i}{\partial S_i} &= 0 \\ \frac{a_i}{Q_i} \cdot exp\left(\frac{-S_i^2}{2 \cdot k \cdot a_i^n \cdot Q_i^m}\right) + \frac{a_i \cdot S_i}{Q_i} \cdot \left(\frac{-2 \cdot S_i}{2 \cdot k \cdot a_i^n \cdot Q_i^m}\right) \cdot exp\left(\frac{-S_i^2}{2 \cdot k \cdot a_i^n \cdot Q_i^m}\right) &= 0 \\ 1 - \frac{S_i^2}{k \cdot a_i^n \cdot Q_i^m} &= 0 \end{aligned} \tag{B.2}$$

This way, we obtain the best forwarding probability of node i:

$$S_i^* = \sqrt{k \cdot a_i^n \cdot Q_i^m} \leftarrow \textit{Strategy that maximizes the utility of node } i \tag{B.3}$$

In the forwarding game, a node i with N neighbours can estimate the average forwarding probability S_i of the other nodes as:

$$S\_i^* = \sum_{\substack{j=1 \\ j \neq i}}^{N} \frac{S_j}{N-1} \tag{B.4}$$

Equilibrium is a term used in game theory to describe a point where each player's strategy is optimal given the strategies of all other players. In this sense, every node can find its best strategy to play the game replacing Equations (6.8) and (B.4) in Equation (B.3), so we have:

$$\begin{aligned} {S_i}^* &= \sqrt{k \cdot a_i^n} \cdot \sqrt{(1 - S\_i)^m} \\ {S_i}^* &= \sqrt{k \cdot a_i^n} \cdot \left(1 - \sum_{\substack{j=1 \\ j \neq i}}^{N} \frac{S_j}{N-1}\right)^{\frac{m}{2}} \end{aligned} \tag{B.5}$$

We design Equation (B.5) with $k = 4$, $n = 3$ and $m = 2$ since these are optimal values, as it is shown in Figure B.1d. Also, we rename the availability factor $\alpha_i = \sqrt{4 \cdot a_i^3}$. Finally, we obtain an expression for the best forwarding probability of node i:

$$S_i{}^* = \alpha_i \cdot \left(1 - \sum_{\substack{j=1 \\ j \neq i}}^{N} \frac{S_j}{N-1} \right) \tag{B.6}$$

Appendix C
VANET simulations platform

The main techniques to analyze the behaviour of a protocol in vehicular network are: analytical modelling, real time physical measurements and computer simulations. First, several studies started to create analytical models of the wireless communication. This allows a rigid analysis of the protocol under research; however, this kind of evaluation is prohibitively complex if we take into account a whole system, thus limiting such evaluations. Also, researchers can use hardware in order to evaluate the performance of the wireless system by conducting several field tests. Despite the potential of real tests, there is yet the need to evaluate them in the long term and at large scale [83]. Due to all these problems, computer simulation appears as the most viable way to test new technologies in VANETs in controlled environments. Without the need to acquire hardware, large scale testing is relative inexpensive and the integrated simulator allows the quantitative analysis of both traffic and wireless networks. The performance of different protocols can be compared through simulation, so it is possible to recognize and resolve performance issues without the need for expensive field tests [35]. This section we start with a description of the main components of our VANET simulator: a network simulator and a road traffic simulator. Next, we describe the VEINS simulator, which we have been using during our research. Finally,

C.0.1 Network simulation

Network simulation is widely used in the investigation, in order to assess the behaviour of the network protocols recently developed. Most wireless network simulators are called discrete-event network simulators. Everything that occurs in the real world is modeled as an event. Examples of discrete-event network simulators are: ns-2 [64], ns-3 [65] and OMNeT++ [8]. For many years, ns-2 was the de facto standard among the protocols network research community. Despite this popularity, ns-2 developers conducted a project to design a new network simulator for networking research. As this tool was designed to replace ns-2, the name chosen for this tool was ns-3. One of the fundamental goals in the ns-3 design was to improve the realism of the models. Also, OMNeT++ is becoming one of the most popular network simulators because it has features of a good simulator. OMNeT++ is an extensible, modular, component-based C++ simulation library and framework which also includes an integrated development and a graphical runtime environment. The motivation of using OMNeT++ in our study is that it offers the combined advantages of ns-2 and ns-3 and is becoming increasingly popular among the protocols network research community. For more information about discrete-event simulation the reader is referred to [31].

C.0.2 Network simulation frameworks

The following major network simulation frameworks have been developed for OMNeT++: INET Framework [5] is an open-source communication networks simulation package, which contains models for several Internet protocols: UDP, TCP, SCTP, IP, IPv6, Ethernet, PPP, IEEE 802.11, MPLS, OSPF, and others. MiXiM [7] supports wireless and mobile simulations. It concentrates on the lower layers of the protocol stack, and provides models of the wireless channel, wireless connectivity, mobility models, models for obstacles and communication protocols mainly at the Medium Access Control (MAC) level. VEINS [11] is an open source Inter-Vehicular Communication (IVC) simulation framework composed of an event-based network simulator (OMNeT++) and a road traffic micro simulation model (SUMO). Network communication is modelled using the simulation package MiXiM.

C.0.3 SUMO simulation

In this section, we introduce the most popular of microscopic road traffic simulation environment called Simulation of Urban Mobility (SUMO) [10]. This simulator is in widespread use in the research community. SUMO is an open-source mobility simulator written in C++ that uses Random Way point path movement and the $Krau\beta$ car-following model. It is highly portable, and allows high-performance simulations of multi-modal traffic in city scale networks. The parameterization of vehicles can be freely chosen with each vehicle following a statically assigned route, a dynamically generated route, or driving according to a configured timetable. Traffic flows can be assigned manually, computed based on demand data, or generated completely at random. The simulation environment supports the automatic import of road networks from a wide range of sources such as: Arcgis, Vissim, OpenStreetMaps, among others.

C.0.4 Vehicles in network simulation. VEINS

We have chosen VEINS as our simulation framework because it offers several important features such as [11]:

1. Allows for online re-configuration and re-routing of vehicles in reaction to network packets.
2. Relies on fully-detailed models of IEEE 802.11p and IEEE 1609.4 DSRC/WAVE network layers, including multi-channel operation, QoS channel access, noise and interference effects.
3. Can import whole scenarios from OpenStreetMap [9], including buildings, speed limits, lane counts, traffic lights, access and turn restrictions.

VEINS is based on two well-established simulators: OMNeT++ and SUMO. Scenarios in SUMO consist in road network and traffic demand. Road network includes streets, highways, traffic light, junctions, among others. Traffic demand provides details of the vehicles such as speed, some physical features for each vehicle, direction, departure and destination time and positions. Road network can be generated by importing a digital road map. In Figure C.1 shows how road network of the city can be imported from the OpenStreetMaps (OSM) database. The vehicles are generated in SUMO and then exported to OMNeT++. All these vehicles are considered as nodes in the network simulator. If any change occurs in the network, VEINS can change the vehicle scenario in SUMO through TraCI (sumo-launchd)

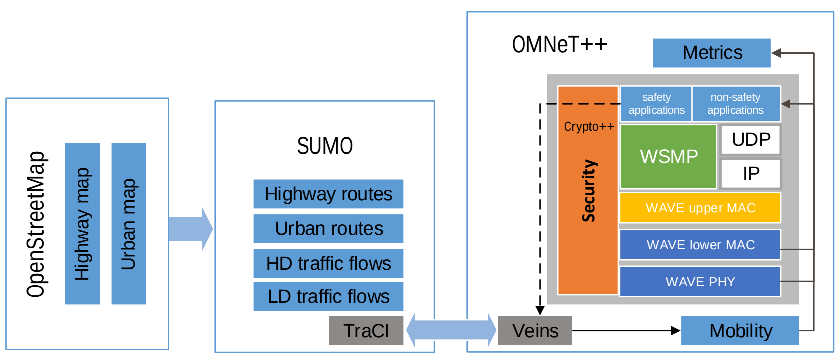


Fig. C.1: VEINS (SUMO - OMNeT++) Simulation mode

According to [83], sumo-launchd is a proxy application that runs as a daemon. It accepts TCP connections from OMNeT++ and SUMO. This script has the following structure of communication between the simulators. OMNeT++ using the TCP protocol sends commands to control the state of the simulation SUMO thus influences the behavior of the vehicles. Next, SUMO executes the commands and responds with information mobility vehicles for simulating OMNeT++. Therefore, SUMO only run commands when OMNeT ++ has finished all simulation processes and the end of the simulation the TCP session is closed. Figure C.2 shows how sumo-launchd work in more details.

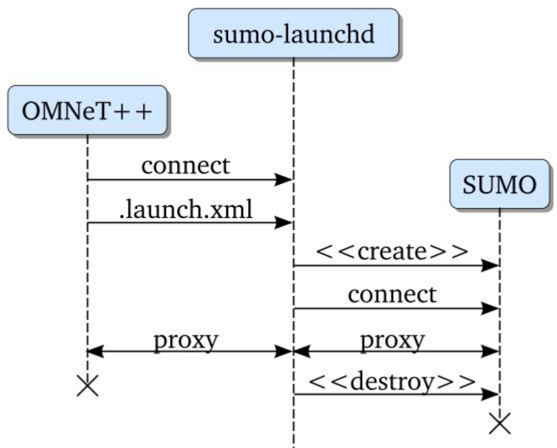


Fig. C.2: Proxy Sumo-launchd [83]

C.0.5 DEMO

We have created an example scenario for our simulations on a map of the city center of Berlin, Germany. This map is obtained from OpenStreetMap and converted into a SUMO network using netconvert and polyconvert tools included in SUMO. We have adopted the recommended options specified in the tool wikipages. This section outlines the software required to run the Demo

Prerequisites to run the demo

1. Install OMNeT++ (recommended version: 4.6).
2. Install SUMO (recommended version: 0.25.0).
3. Clone this repository (`https://github.com/7d5791/dataDissemination`). (or download the zip file)
4. If you are on Linux and use the command line:
   a. switch to the root of the repository and type
   b. `make makefiles`
   c. `make`
   d. go to the folder `dataDissemination/VoDi-GameTheory-Msgs/examples/veins/` and run the example.
5. If you are on Linux and use the OMNeT++ IDE:
   a. File →Import →General/Existing Projects into Workspace →Next
   b. select the Veins directory as root and tick the project →Finish
   c. Project →Build All (or CTRL+B)
   d. go to the folder `VoDi-GameTheory-Msgs/examples/veins/` →rightclick on `omnetpp.ini` →Run As →OMNeT++ Simulation
6. This demo requires `sumo-launchd` to be started and listening for connections on a TCP socket, e.g. using `/src/veins/sumo-launchd.py -vv`.

In the `omnet.ini` configuration file, we have added a configuration section for each dissemination scheme with example parameter settings. To test one of these schemes, you need to run the simulation with its corresponding configuration section. At the end of the simulation, the disemination results are displayed in the simulation log showing various metrics such as packet delivery ratio (PDR), average packet delay (APD) and number of collision packets (NCP).

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