IRONMAN: Infrastructured RSSI-based Opportunistic routiNg in Mobile Adhoc Networks

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***Abstract*—V2X technologies are based on heterogeneous and safety-related applications that rely on broadcast messages, which are typical in V2V communications, and to unicast messages, which are, instead, typical in V2I/I2V communications. To ease unicast communications from the infrastructure to the vehicle, like rescue operations, addressing the challenging routing aspect for VANETs, we designed an Infrastructured RSSI-based Opportunistic routiNg algorithm for Mobile Adhoc Networks (IRONMAN), also focusing on the energy consumption of the solution developed. IRONMAN takes opportunistic routing decisions based on the RSSI calculated by the Road-Side Units (RSUs), instead of the classical GPS-based solutions. Through a real testbed, we demonstrate that IRONMAN outperforms standard Linux-based routing solutions for ad-hoc networks, like BATMAN and HWMP, providing almost optimal goodput without adding any overhead related to the routing decisions.**

***Index Terms*—Routing, VANET, V2X, IEEE 802.11p.**

I. Introduction

In the last decade, an intense effort of both academia and industry has focused on addressing the challenges of Vehicular Ad-hoc Networks (VANET) [1]–[3], intending to extend data network connectivity practically and efficiently even in vehicular environments, with the goal to exploit such a technology for safety-related applications and, in general, efficiently use them in post-disaster environments. So the aim has been the introduction of Information and Communication Technologies (ICT) in the transportation of humans and goods to improve individual safety [4], [5], traffic management, congestion control [6], etc., pointing in the direction of Intelligent Transport Systems (ITS) [7]. To deal with it, several standards have been proposed for both the technology and the communication stack. For what concerns the technological aspect, the most important standards designed are C-V2X, which extends the cellular network of 4G/5G for vehicular purposes, and IEEE 802.11p, which is the extension of standard IEEE 802.11 family for vehicular environments [8], [9]. This paper focuses on the IEEE 802.11p solution due to the presence of several mature devices that enable the creation of real testbeds, as well as the easy use of the unlicensed spectrum of IEEE 802.11 standards. Both technologies define the physical and MAC layers of the communication stack.

Dealing with the remaining layers, the ETSI stack has been designed as the European network standards. The ETSI stack refers to standard IP, UDP, and TCP for the network and transport layers, together with the GeoNetworking protocol, while, at the application layer, it defines a large class of messages. Two over all are the Cooperative Awareness Message (CAM), periodical messages also considered in this manuscript, and Decentralized Environmental Notification Message (DENM), event-driven messages. V2X technologies support various applications that rely either on broadcast or unicast messages. The former are typical in Vehicular to Vehicular (V2V) communications while the latter, are typical in Vehicular to Infrastructure (V2I) or Infrastructure to Vehicular (I2V) communications.

According to the ETSI standards, vehicles are asked to periodically broadcast information like position, speed, and other specific metrics through the CAM messages. These packets are used by the GeoNetworking protocol to support routing based on the positions of the vehicles through the GPS coordinates [10]; this approach might not be optimal due to the presence of multiple obstacles in vehicular environments [11]; therefore, we investigated a different approach that refers to the Received Signal Strength Index (RSSI) instead of the actual GPS position.

The CAM packets can be used by each Road-Side Unit (RSU) to collect the RSSI of each vehicle. Based on such an assumption, we developed IRONMAN, an Infrastructured RSSI-based Opportunistic routiNg algorithm for Mobile Adhoc Networks. IRONMAN consists of a centralized control system that enables the infrastructured part of the network to initiate unicast communications, with the desired vehicle without invoking or trigger specific routing messages to calculate the vehicle position.

In this paper, we present the IRONMAN algorithm, and the results obtained comparing IRONMAN with other state-of-the-art routing protocols for ad-hoc networks available on Linux systems. We compared IRONMAN with a possible broadcast-based strategy, also developed by us, to ensure to reach a vehicle through the surrounding RSUs, together with two Linux algorithms: BATMAN (Better Approach To Mobile Adhoc Networking) [12]–[14] and HWMP (Hybrid Wireless Mesh Protocol) [15]–[17], which are the default for ad-hoc and mesh networks respectively. The comparison with the different algorithms has been performed through a real testbed. The use of RSSI information to track each vehicle through the RSUs by processing the available CAM messages let us avoid specific routing messages with the vehicles, reducing the overhead of the protocol and the power consumption of the solution itself, which is a fundamental aspect in VANET. By doing this, IRONMAN also helps to manage the duty-cycle of On Board Unit (OBU), which is a challenging task.

A. Contribution

This paper solves the problem to route packets from a core wired network to a wirelessly connected vehicle. The solution proposed is named IRONMAN, a routing algorithm that does not introduce any overhead by making decisions at the edge of the wired/wireless network without modifying the vehicles' behavior at all. Results show that IRONMAN is a green solution that outperforms two Linux-based variants for real testbeds.

The rest of the paper is organized as follows: Section II describes the related work, while Section III focuses on the system view of our solution. Then, in Section IV is described the real testbed that we used to collect the results available in Section V. Finally, Section VI concludes the paper.

II. Related work

The idea of using RSSI to perform network operations is not new. Several works have taken advantage of the RSSI information to localize a device, this has been a valid possibility for Wireless Sensor Networks [18], [19], where the hypothesis consider a static scenario, while in MANET, which is a more challenging environment due to mobility, the RSSI-based localization still carries significant errors [20]–[23].

More fruitful use of the RSSI information in VANET has been done through the definition of several routing algorithms. Indeed, one of the most investigated areas for what concern the routing problem in a vehicular environment has been the V2V message dissemination problem for broadcast messages, which is the base for applications like GeoNetworking [24]. Several solutions related to this problem have been proposed, some of them are based on RSSI [25], while others are based on the network density [26], [27]. A different way to deal with the same problem is, instead, to use the GPS information to know the vehicle position and enable greedy solutions for the routing strategy. Solutions that focus on this approach are [10], [28].

Another, yet different approach related to the routing problem has been proposed for low-power and lossy networks (RPL). These solutions are tailored on IEEE 802.15.4 technologies but introduce interesting insights considering the energy consumption problem [29], in particular, in [30], which is an RSSI-based version for an RPL algorithm.

The hybrid approach of wired/wireless networks for vehicular environments have been considered for solving routing problems, but from a different perspective with respect to our work. It is the case of [31] in which the wired part of the network is the intra-network system of a car, and the focus of the work is on load balancing between the buses used for internal communications.

Between the routing algorithm available on Linux for the automatic path selection at layer 2, based on link quality, there are BATMAN [12]–[14] and HWMP [15]–[17], which are the default solution for MANET and mesh networks respectively. Both of the algorithms have been already deployed also on VANETs and, according to [32], BATMAN is better than HWMP for vehicular environments.

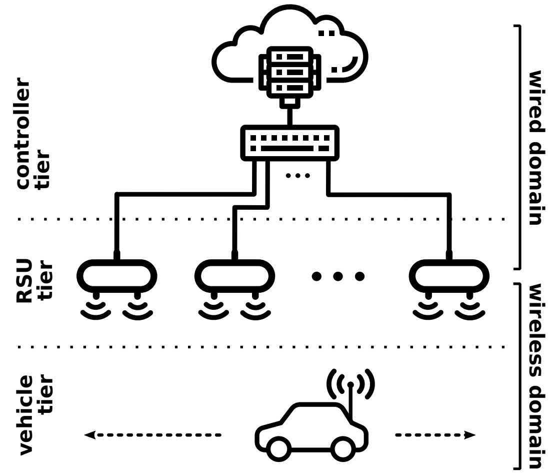

Fig. 1: IRONMAN's system view.

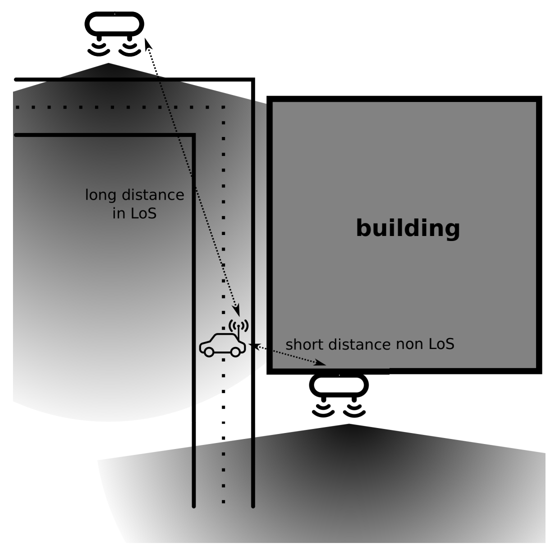

Fig. 2: Static obstacle example.

III. System

In this section, we present the system view of our solution, which is depicted in Figure 1. We considered a hybrid vehicular network in which there is both the presence of a wireless and wired connectivity. The wireless network is used to connect vehicles to each other and perform V2V communications and to connect vehicles to the RSUs. At the same time, we also consider the presence of the wired, and

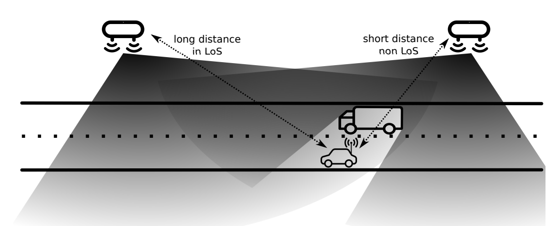

Fig. 3: Dynamic obstacle example.

Algorithm 1: IRONMAN: RSU tracker.

foreach *k-th CAM message $m_{j,k}$ received from V_j* **do**
  compute RSSI $r_{j,k}$ for the received message;
  store the couple $(V_j, r_{j,k})$;
end

infrastructured, network which enables the use of a controller that manages and orchestrates the network and the RSUs. Besides, the presence of the controller enables the introduction of future SDN services for vehicular environments [33]–[37].

While V2V communications rely mainly on broadcast-based messages and protocols, services and communications between the infrastructure (the controller in our case) and a vehicle can be unicast. Unicast applications from infrastructure to vehicle require a routing structure to know the proper RSU through which to reach the desired vehicle. Back to the V2V messages, there is a typology of messages called Cooperative Awareness Messages (CAM) which are part of the ETSI standard, that each vehicle should deploy in order to inform the surrounding nodes, in a broadcast way, regarding the speed, the position, and other metrics [38]. These messages have a dissemination frequency of 10Hz and can be used to take opportunistic decisions based on the information carried by them.

A typical solution for general routing in the mobile scenario could be to use these CAM-based GPS information [39], [40] but, according to [41], position-based protocol based on CAM suffers inefficiency of this message dissemination, where more than half of the transmissions are not relevant and do not significantly impact on the applications' quality. Our solution takes opportunistic decision based on the RSSI signal captured through CAM messages, rather than using the vehicles' positions. In our approach, all the CAM messages are used and exploited efficiently.

The inefficiency of CAM exploitation is not the only problem related to GPS routing; even the high dynamism of the network changes the topology fast, and the GPS information gives not always the optimal route. These examples are depicted in Figure 2 and 3. In Figure 2, the optimal coverage is not provided by the closest RSU concerning the physical distance, the presence of the building let prefer another RSUs, more distant but in line-of-sight. In Figure 3, a truck hides the closest RSU, let preferring, again, a farther RSU but in line-of-sight for the communication. While a GPS-aware algorithm can address the former through knowledge of static obstacles (e.g., RSU and building positions), the latter can not be addressed due to the unpredictable presence of mobile obstacles.

A. IRONMAN Algorithm

We consider a set of road side units $\mathcal{RSU} = \{RSU_1, \ldots, RSU_n\}$ and a set of vehicle $\mathcal{V} = \{V_1, \ldots, V_m\}$. Let RSU_i be a generic RSU and V_j be a generic vehicle. If RSU_i receives a CAM message $m_{j,k}$, which is the k-th CAM message broadcasted by V_j, it registers the $r_{j,k}$ as the RSSI associated to message $m_{j,k}$, and store the couple $(V_j, r_{j,k})$, as reported in the Algorithm 1, executed continuously on each RSU. During periodical intervals, set at 1 second in our system, each RSU_i creates an ethernet packet (or more if needed) containing the couples $(V_j, r_{j,k})$ and send it the controller through the wired interface according to Algorithm 2. The controller, instead, computes the average RSSI $r_{i,j}$ of each vehicle V_j for any given RSU_i by using the information collected by the RSUs and sets (or updates), for each vehicle V_j, the RSU_i with the best RSSI $r_{i,j}$ as the route to reach the vehicle as showed in Algorithm 3. The description does not report the corner cases like a vehicle or RSU that get faults, missing CAM, vehicle moving out of coverage, and controller initialization: for those examples, we redirect to the public IRONMAN source [42].

Algorithm 2: IRONMAN: RSU update, executed every time interval (default: 1 second).

if *memory not empty* **then**
  foreach *V_j stored* **do**
    Send all the couples $(V_j, r_{j,k})$ to C;
  end
end
clean all the couples (V,r): empty memory;

Algorithm 3: IRONMAN: Controller.

foreach *report received from RSU_i* **do**
  foreach *V_j in the report* **do**
    compute the new average RSSI $r_{i,j}$;
    let RSU_w be the current route for V_j;
    if $r_{i,j} > r_{w,j}$ **then**
      update the route to V_j through RSU_i;
    end
  end
end

IV. TESTBED

Our testbed involved five nodes, one controller `C`, three RSUs, and one vehicle `V`; its physical representation is depicted in Figure 4. The controller is deployed in a general-purpose PC running a Linux Debian distribution as the operating system, it is connected through an ethernet switch to the RSUs. The RSUs, as well as the vehicle, are modeled with Arduino Yun devices. The reason why we choose Arduino Yus is that it is a low-cost device featuring a Qualcomm Atheros AR9331 chipset that allows using the `ath9k` driver for the wireless interface. This particular driver is necessary to perform real IEEE 802.11p transmissions, together with a Linux kernel version higher than 4.4. Flushing the Arduino Yun with OpenWrt/LEDE version 17.01.6 guarantees a Linux kernel version of 4.4.153 that enables IEEE 802.11p wireless network card configurations.

To compare IRONMAN with existing open solutions for ad-hoc networks we configured each node to run also BAT-

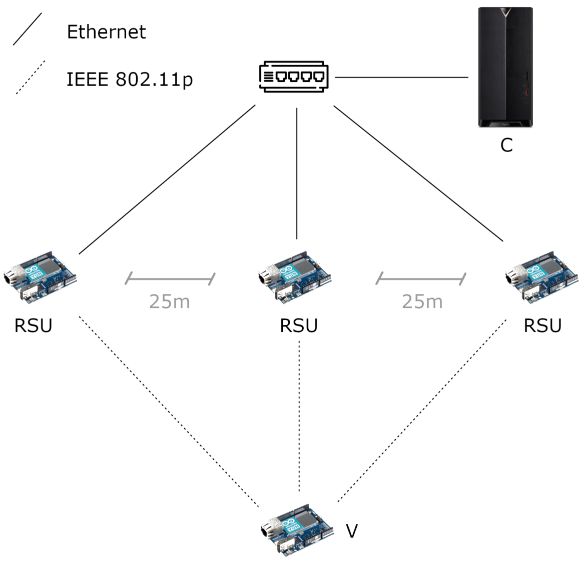

Fig. 4: Testbed topology.

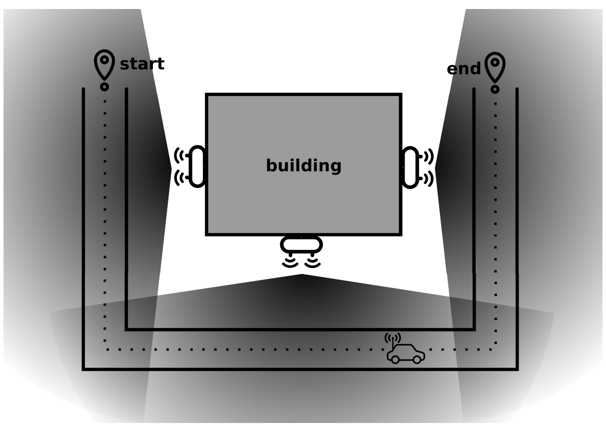

Fig. 5: Urban topology.

MAN [12]–[14] and HWMP [15]–[17], together with another solution, customized by us, which is an attempt to reach the vehicle through all the RSUs in a broadcast way, converting the unicast transmission in broadcast transmission, and relaxing the hypothesis related to the vehicle position, allowing all the surrounding RSUs to transmit the packet to the vehicle, with the goal of increasing the outage probability. Scripts related to the configuration of BATMAN and HWMP, together with details on the broadcast solution, are also available in [42].

Our tests are organized in two different topologies; the first

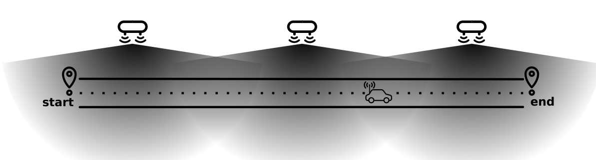

Fig. 6: Highway topology.

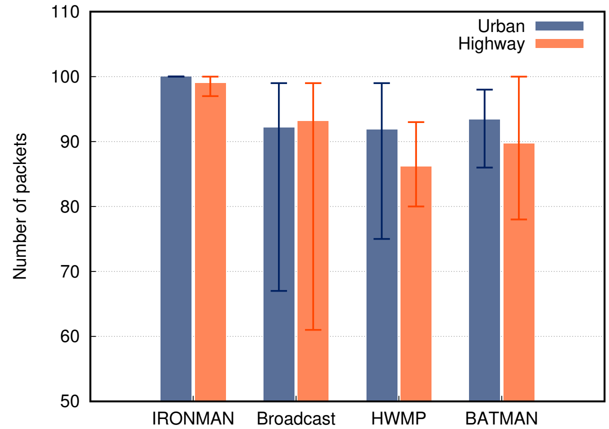

Fig. 7: Goodput of 2 topos.

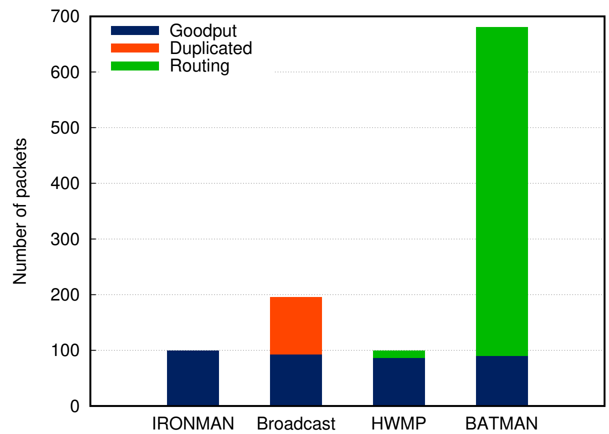

Fig. 8: Messages' overhead.

one models an urban scenario where the RSUs surrounds a building (Figure 5), while the second one models a highway scenario where the RSUs are in line-of-sight (Figure 6). All the experiments are organized as follows:

- `V` moves from the `start` to the `end` of the path, back and forward, at 50km/h in the urban scenario and 80km/h in the highway[1];
- `V` broadcasts standard CAM message at a frequency of 10Hz;
- `C` transmits 100 packets at 1Hz frequency to `V`;
- The technique and the route from `C` to `V` changes for each test between the four possibilities investigated.

We perform 10 repetitions of each test to collect also statistical min-max deviations.

V. Results

In this section, we analyze the results collected during our tests, comparing IRONMAN, HWMP, BATMAN, and the customized broadcast solution described in Section IV. As a first result, we report in Figure 7 the goodput registered during

[1]The reduced speeds have been preferred in order to be able to perform the field-tests with drones, and properly scale the network size to the limited coverage of the Arduino Yun devices.

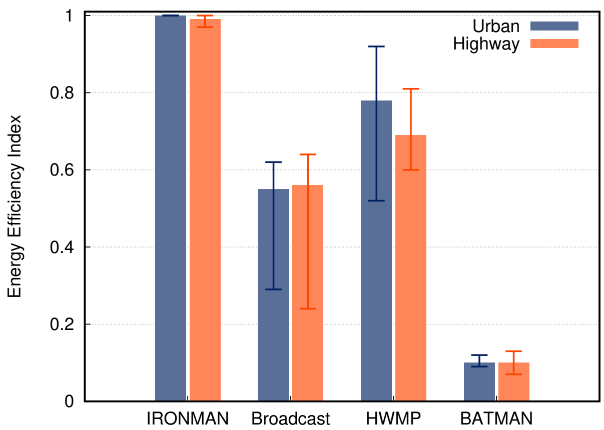

Fig. 9: Energy efficiency index.

the experiments, grouped by the two topologies investigated. We are considering that the number of packets that C transmits to V is 100, so the number of correctly received packets gave us also the goodput percentage. The first consideration in Figure 7 is that IRONMAN is able to guarantee quite optimal performance, both in terms of goodput and min-max variance, reported through the error-bars of the histograms. BATMAN performs slightly better than HWMP, has expected from a previous independent work [32]. A non-immediate output, instead, is provided by the broadcast solution. The goal of maximizing the outage probability by concurrently transmit the same packet from more RSUs has the drawback to generate collisions and, consequently, the loss of some packets. This because the RSUs are not in perfect mutual-coverage, and the transmission of broadcast packets does not rely on the Request-To-Send/Clear-To-Send (RTS/CTS) pattern, leading to possible hidden-terminal problems. Indeed, this issue is slightly more remarked for the urban scenario, where the RSUs are not in line-of-sight. This phenomenon also depends on unwanted time-synchronization between the RSUs; this is why even the min-max variance between all the runs is larger with respect to the other solutions. While the broadcast issues are slightly attenuated moving from the urban to the highway scenario, for all the other protocols, the urban scenario manifests better results, due to the lower speed of the urban scenario with respect to the highway one.

With Figure 8, instead, we focus on the wireless overhead imposed by each solution. Considering the remarkable similarity of the two topologies' results, as well as the small min-max variance, we report a single stacked histogram. Figure 8 reports the number of packets correctly received, together with the duplicate packets and the routing messages. The former quantity only belongs to the Broadcast algorithm, and it captures the case in which the i-th packet transmitted by C is correctly received by V through more than one RSU, while the latter quantity belongs only to the real routing algorithms that periodically exchange data, on the wireless interface, to maintain the local wireless network topology. It is important to notice that IRONMAN does not produce routing packets, this because there is no specific routing-purpose exchange of packets between the vehicle and the RSUs. The reason has been described in Section III and consists of the opportunistic use of the already provided CAM messages. Continuing, BATMAN is the protocol that introduces the higher overhead, which is the price to pay to have a higher goodput with respect to HWMP. We consider the results reported in Figure 8 strongly related to the energy consumption of each algorithm; this is true for the vehicle, in which a smaller number of messages received helps in the duty-cycle management, but it is true also for the RSUs, in which the messages exchanged on the wireless interface have a stronger impact on the energy consumption with respect to the messages exchanged on the wired interface.

We then included both of these results of Figure 7 and 8 defined an Energy Efficiency index (E_i^2) in this way:

$$E_i^2 = \underbrace{\frac{p_{data}}{100}}_{Goodput} \cdot \underbrace{\frac{p_{data}}{p_{all}}}_{Overhead} = \frac{p_{data}^2}{100 \cdot p_{all}} \tag{1}$$

where p_{data} is the number of correctly received data packets and p_{all} is the total amount of received packets, including duplicates and routing packets, if present. The left part of the equation is the percentage goodput, and it is a value in the range [0,1], the same is true for the right part of the equation that represents the overhead and is a value in the range]0,1]. The product of these two quantities gives E_i^2, which is then in the range [0,1]. With this variable, we capture both the figures of merit that impact on energy consumption. We report the E_i^2 computed during our experiments in Figure 9. By modeling the energy consumption, the evaluation of the HWMP algorithm, with respect to BATMAN, changes. Indeed HWMP has a slightly lower performance in terms of goodput, but there is a large gap between the protocols, in terms of overhead, that is captured by E_i^2. To conclude, IRONMAN still reports almost optimal values also for the E_i^2 metric, due to the high goodput and the absence of specific routing packets, resulting in a promising protocol for vehicular and general ad-hoc networks.

VI. Conclusions

We have presented IRONMAN, Infrastructured RSSI-based Opportunistic routiNg in Mobile Adhoc Network, which is an algorithm that takes opportunistic decisions based on the signal strength of the CAM messages generated by the vehicles. Our solution has been compared with routing algorithms available as the state-of-the-art of Linux kernels for ad-hoc environments. We represented two possible scenarios of urban and highway topologies for the infrastructured part of the network composed of the RSUs. Through real tests, IRONMAN showed an almost optimal performance for both the goodput reached by the network and also the low energy consumption due to the absence of duplicate packets, loss, and dedicated routing messages on the wireless interface. Our experiments highlight that IRONMAN outperforms other available protocols like BATMAN, HWMP, and a simple broadcast solution.

Future works will investigate the performance of IRONMAN over extensive testbed involving more powerful nodes, both in terms of coverage and processing capabilities.

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