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Intelligent Epidemic Routing for Cooperative IEEE 802.11 Networks

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***Abstract*—In densely populated areas IEEE 802.11 technologies are becoming ubiquitous in response to the increasing number of fixed access points and the multitudes of wireless smart phone users. The Intelligent Wireless Router (IWR) protocol is proposed for the fixed nodes (home wireless routers) of a cooperative IEEE 802.11 community network. Combined with a knowledge base, this protocol selects the best fixed node to initiate a spray-and-wait controlled *epidemy* among the mobile nodes (laptops and smart phones) that belong to the community. IWR's goal is to deliver delay-tolerant data messages from a particular source mobile node to another particular destination mobile node using the Internet as a backbone to control the network overhead, and consequently lowering overall energy consumption. Simulation results show that the IWR protocol can deliver the same number of messages of traditional epidemic routing causing less network overhead with a tolerable end-to-end delay.**

***Index Terms*—epidemic routing, cooperative IEEE 802.11, delay tolerant networks**

I. Introduction

Within the past few years, the Internet has experienced a critical shift. The explosion of wireless mobile computing and the exponential growth of users in densely populated areas enables the general public to become providers of communication services [1]. In a cooperative IEEE 802.11 community network, the wireless medium is shared freely and transparently among users. One example is the FON [2] community. In order to be part of the community, one has to acquire a IEEE 802.11 home wireless router. FON members have free Internet access at any FON access point. Figure 1 shows how FON access points became ubiquitous in the center of Madrid.

The main motivation of this paper is to investigate a different Delay Tolerant Network (DTN) scenario where the user's wired subscribed Internet connections are used as a backbone to diminish the delay and control the network overhead of traditional DTN epidemic routing [3]. The Intelligent Wireless Router (IWR) protocol is proposed for the fixed nodes (home wireless routers) in a cooperative IEEE 802.11 community network. Combined with a knowledge base, this protocol aims to select the best fixed node to initiate an *epidemy* among the mobile nodes (laptops and smart phones) that belong to a wireless cooperative community.

The Time Ontology in Web Ontology Language (OWL) [4] was used to model the knowledge acquired by the agents

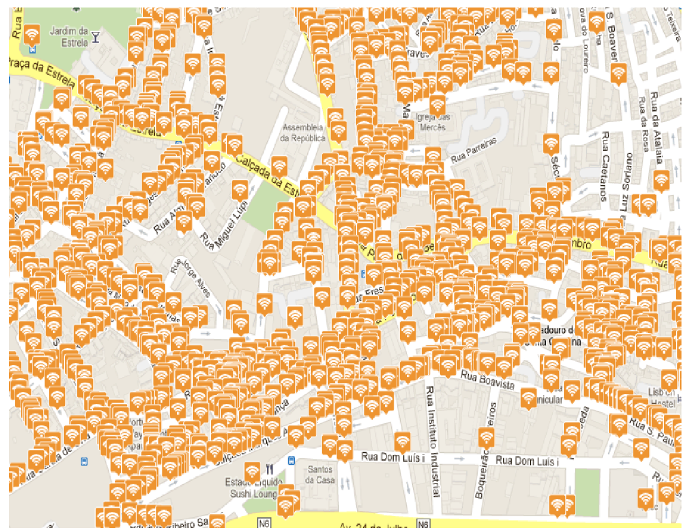

Fig. 1. FON access points in Madrid [2].

(home wireless routers) when within wireless range of mobile nodes (smart phones and notebooks). Such knowledge is stored in a central entity in the Internet, the Knowledge Base server. The Knowledge Query Manipulation Language (KQML) [5] was used to model the knowledge exchange between the agents and the central entity.

The IWR protocol differs from traditional DTN routing proposals in two aspects: i) it uses an ontology knowledge base compatible with a proper knowledge manipulation language to support routing, and ii) it uses the Internet to improve performance, and consequently lowers overall mobile device energy consumption. Simulation results show that the IWR protocol can deliver the same number of messages of traditional epidemic routing causing less network overhead with a tolerable end-to-end delay.

The order of the paper is presented as follows: Section II incorporates related work and Section III describes the network scenario. The IWR protocol is presented in Section IV, simulation setup and results are described in Section V, and finally, Section VI presents conclusions and future work.

II. Related Work

A basic classification for delay-tolerant networks routing solutions is whether or not the protocol creates replicas of

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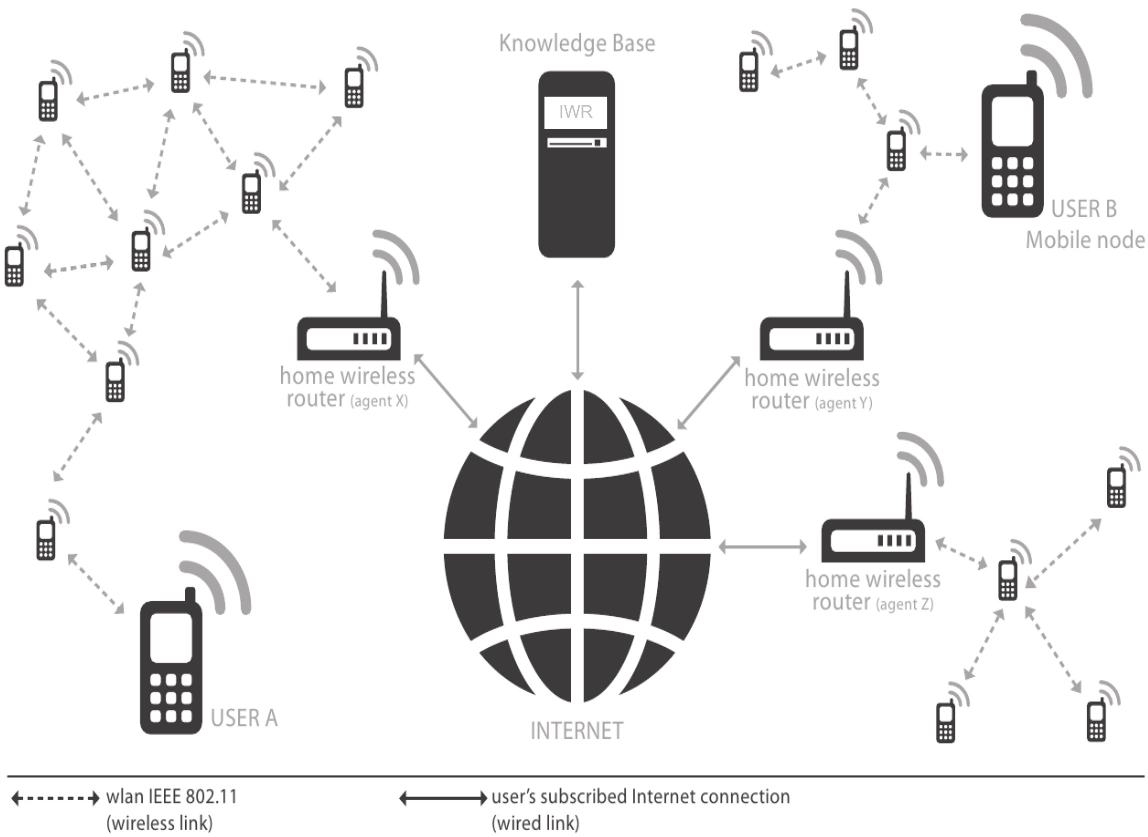

Fig. 2. Network Scenario.

messages. DTN routing solutions that never replicate a message are considered forwarding-based, whereas protocols that replicate messages are considered replication-based [6].

In forwarding-based DTN protocols, only a single copy of a message exists in storage in the network at any given time, preserving network resources. Forwarding-based approaches do not allow for sufficient message delivery rates in many delay tolerant networks. An interesting study about the limitations of forwarding-based DTN routing solutions can be found in [7].

Replication-based protocols have obtained much attention from the research community due to their greater message delivery rates. Multiple message copies exist in the network, yet only one must reach the destination [3]. Replication-based routing solutions can be sub-classified in flooding-based and quota-based solutions [8]. In flooding-based solutions, if storage resources and mobility allow, it is possible for every node in the network to have a replica of the message. The quota-based solutions intentionally limit the number of replicas. Waste of network resources, scalability, and congestion are important concerns present in replication-based routing.

Network resource efficiency can be improved using Spray-and-wait (SnW) [9]. This quota-based DTN routing solution attempts to limit the number of possible replicas of a given message. The upper bound number of message copies in the network, is represented by *L*. The source of a new message "sprays" (delivers) *L* copies to distinct DTN nodes. The "wait" phase begins when a custodian node receives one of the *L* copies and continues until the destination is encountered.

The IWR solution uses an ontology knowledge base compatible with a proper knowledge manipulation language to select the best fixed node to initiate an IEEE 802.11 $epidemy$ among the mobile nodes. Together with SnW, the IWR protocol uses the Internet as a backbone to diminish the delay and control the network overhead on the wireless network.

III. Network Scenario

The network scenario considered in this work relates to a regular user roaming in a metropolitan area covered by a specific wireless cooperative community. The users registered in the system agree to forward data to other registered users epidemically by IEEE 802.11 technologies. Though, users of the same community share storage capabilities, energy resources and wireless connectivity. The users may also agree to share their subscribed Internet wired connection using their home wireless router, as depicted in figure 2. A video illustration of the network scenario (and consequently, the simulation scenario) is available at [10].

The epidemic routing only occurs in the wireless part of the network. It is modeled as a proactive ad hoc routing solution, which means that each node periodically announces its presence on the network through a $control\_message$. When two nodes are within wireless range, they replicate the

DTN data messages properly, according to the spray-and-wait DTN routing solution.

Such new spontaneous communication networks are based on the idea that the dissemination of information may augment the user life experience. For instance, by means of such spontaneous setting, the members of the wireless community can get News, Traffic information, or even exchange messages independently of their location and terminal, increasing the pervasiveness of the community, and consequently the Internet itself.

:last	
a	:Instant;
:inXSDDateTime	(e.g 2011-06-24T16:29:00).

TABLE I
THE LAST TIME THAT THE AGENT HEARD ABOUT A SPECIFIC MOBILE NODE (TIME ONTOLOGY IN OWL).

:meeting#0	
a	:Interval;
:hasBeginning	:meetingStart#0;
:hasEnd	:meetingEnd#0;
:hasDuration	:meetingDuration#0.
:meetingStart#0	
a	:Instant;
:inXSDDateTime	(e.g. 2011-06-24T16:21:03).
:meetingEnd#0	
a	:Instant;
:inXSDDateTime	(e.g. 2011-06-24T16:21:58).
:meetingDuration#0	
a	:DurationDescription;
:seconds	(e.g. 55).
:meeting#1	
a	:Interval;
:hasBeginning	:meetingStart#1;
:hasEnd	:meetingEnd#1;
:hasDuration	:meetingDuration#1.
:meetingStart#1	
a	:Instant;
:inXSDDateTime	(e.g. 2011-06-24T16:26:00).
:meetingEnd#1	
a	:Instant;
:inXSDDateTime	(e.g. 2011-06-24T16:29:00).
:meetingDuration#1	
a	:DurationDescription;
:seconds	(e.g. 180).

TABLE II
A MEETING BETWEEN THE AGENT AND A MOBILE NODE (TIME ONTOLOGY IN OWL).

IV. THE IWR PROTOCOL

The Intelligent Wireless Router (IWR) protocol's goal is to deliver delay-tolerant data messages from a particular source mobile node to another particular destination mobile node using the Internet as a backbone to diminish the delay and cause less network overhead among the members of a wireless IEEE 802.11 community.

The Time Ontology is used to model the knowledge acquired by the agent (home wireless routers) when within wireless range of mobile nodes (smart phones and notebooks). This knowledge is forwarded to and stored by the Knowledge Base server. The KQML is used to model the knowledge exchange between the agents and the Knowledge Base server.

A. Knowledge Base

The Time Ontology provides a vocabulary for expressing facts about topological relations among $Instants$ and $Intervals$. Such relations can be further represented together to convey $Durations$ and $Date\text{-}time$ information. This vocabulary allows the expression of two temporal entries concerning the meetings between an agent (home wireless router) and a mobile node (smart phone or notebook). Such temporal entries are presented as follows: i) The last time that the agent heard about a specific mobile node. Whenever an agent receives a $control\_message$ from a mobile node, it updates this knowledge base entry. The entry is expressed in Table I. ii) A meeting between the agent and a mobile node always has a $Beginning$, an End, and a $Duration$. The entry is expressed in Table II.

In Tables I and II, the Knowledge Base states that: the last time that a specific agent (home wireless router) heard about the mobile node was at 2011-06-24T16:29:00, there was a total of two meetings between both in the current window period, and the nodes were connected so far 235 seconds, the sum of all meetings duration.

The window period is the only parameter in IWR. It determines how important the meeting is at the time of best agent selection. If the meeting took place during the current window period, it is more important to the best agent selection process.

B. Knowledge Exchange

The KQML was used to model the knowledge query between the agents (home wireless routers) and the Knowledge Base server. Such communication protocol is designed to support run-time interaction and knowledge exchange among intelligent agent systems. Whenever an agent needs to start an $epidemy$ in the wireless community, it may ask the following question to the Knowledge Base server: what is the home wireless router (agent) that is more likely to be within wireless range of the DTN data message destination mobile node? The query and the possible agents answers are expressed in Table III.

Query:	
(ask	
:sender	:(e.g. agent-y);
:receiver	:knowledge_base_server;
:language	:prolog;
:ontology	:time ontology in owl;
:content	:"?-bestAgent('mobilenode_*x*', *any*)".)
Answers:	
(tell	
:sender	:(knowledge_base_server);
:receiver	:agent-y;
:language	:prolog;
:ontology	:time ontology in owl;
:content	:"[bestAgent('mobilenode_*x*', 'agent-z')".)
(deny	
:sender	:(knowledge_base_server);
:receiver	:agent-y.)

TABLE III
THE QUERY AND THE POSSIBLE ANSWERS IN KQML.

Here, ask, $tell$ and $deny$ are the performatives. The point of this utterance is that the speaker, agent-y, is asking the Knowledge Base server for a response to the query contained in the message :content. The :language indicates that the

:content is expressed in Prolog [11], and the :ontology used to express the knowledge is the Time Ontology in OWL. In this particular answer, the Knowledge Base server $tells$ agent-y that agent-z has an open connection (is in a meeting) with the mobile node x. In this case, the $epidemy$ has not even started. Agent-y simply forwards the DTN data message to agent-z, because the last one is connected to the message destination (mobile node x). A $deny$ answer is issued when the Knowledge Base server has no entries about the message destination (mobile node x).

The Knowledge Base server answers the question after running the proposed Algorithm 1, where:

A: is the vector of known agents;

x: is the DTN data message destination address;

$meet(a, x)$: is a meeting between an agent a and a mobile node x;

```
forall known agent in A do
    if a.isConnectedTo(x) then return (a);
    forall meet(a, x) do
        Calculate sum(meet(a, x).meetingDuration) in
        the current window period;
        return (a.maxMeetingDuration);
    end
    if (a.maxMeetingDuration) == 0; then
        forall meet(a, x) do
            Calculate
            sum(meet(a, x).meetingDuration) total
            meetings duration;
            return (a.maxMeetingDuration);
        end
    end
    if (a.maxMeetingDuration) == 0; then
        return (deny);
    end
end
```

Algorithm 1: What is the home wireless router (a) that is more likely to be within wireless range of the DTN data message destination (x)?

V. SIMULATION SETUP AND RESULTS

The simulations were performed using the OMNeT++ network simulator version 4.1 with the INETMANET framework [12]. The IEEE 802.11 Layer in ad-hoc mode was used with Nakagami-m [13] propagation model on the physical layer. The playground size used was 2000m x 2000m. All nodes have synchronized clocks [14]. The data was collected over 30 simulation runs for each scenario. DTN data messages of 140 characters, a "tweet" [15], were generated in each mobile node using random mobile destination addresses. The parameters used in the simulations are given in table IV.

A. Setup

UDelModels [16] is a suite of tools for simulating urban mesh networks that includes a simulator of realistic urban mobility. The mobility simulator is able to simulate daily life pedestrian dynamics (e.g. arrival times at work, lunch time, breaks) and vehicle traffic dynamics (e.g. traffic lights). Most of the related work presented here were evaluated in simple mobility models, especially Random Way Point or vehicular mobility (e.g. Manhattan mobility). IWR was evaluated in a complex urban mobility model, where the pedestrian nodes interact directly with vehicular nodes in an urban area.

Simulation Parameters	
General	
Simulation time	4000s
DTN data message size	140 bytes
DTN buffer size	7500 bytes
Playground size	2000m x 2000m
Nakagami-m Propagation model	$m = 1$
Wired Channel delay (Internet delay[1])	uniform(1s,2s)
$ctrl\_message$ period (proactive ad-hoc parameter)	uniform(5s,10s)
Scenario - 1	
N^{o}of pedestrian	15
N^{o}of cars	10
N^{o}of home wireless routers (agents)	10
Scenario - 2	
N^{o}of pedestrian	30
N^{o}of cars	10
N^{o}of home wireless routers (agents)	10
Urban Mobility Model Parameters	
City	RealisticCitiesV1.2 - Chicago2000m
Pedestrian Speed (min/max)	0.7-3 m/s (considering cyclists)
Car Speed (min/max)	6-18 m/s
Fraction where pedestrian appear (Room)	0.5
Fraction where pedestrian appear (Parking lot)	0.5
Fraction of nonworkers	0.5
Traffic Lights	On
IWR Parameter	
Window Period	100s
Spray-and-wait Parameter	
N^{o}replicated msgs allowed in the network(L)	10

TABLE IV
SIMULATION PARAMETERS.

The application layer on mobile nodes generates DTN data messages to random destination nodes every 30 seconds. To simulate Internet delay, the wired channels were setup accordingly[1]. Whenever a DTN data message is replicated to one of the agents the IWR protocol starts. It is responsible for deciding which agent shall best improve the DTN message $epidemy$ among the mobile nodes.

Delivery Rate				
	F. Epidemic	IWR	Tr. Epidemic	Tr. SnW
Scenario-1	92.67%	91.58%	84.12%	81.13%
Scenario-2	92.71%	91.56%	84.44%	80.01%

TABLE V
AVERAGE DELIVERY RATE.

B. Results

The IWR routing solution was compared to three other approaches: i) Full epidemic routing: this uses the Internet as a backbone, when two nodes are within wireless range (or are wired connected, in the case of home wireless routers) they replicate the DTN data messages properly, avoiding

[1]According to Verizon Co., the mean ping delay on the Internet nowadays is less than 500 (ms).

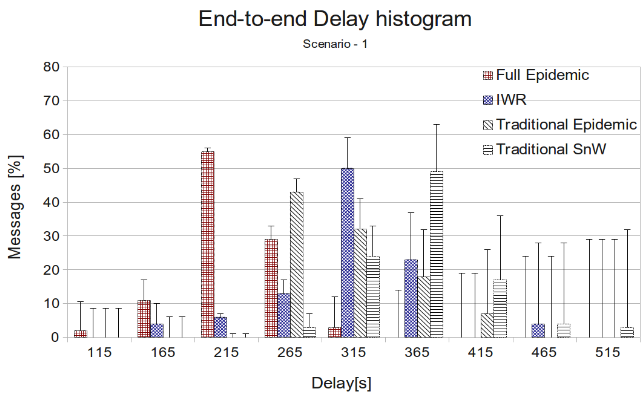

Fig. 3. End-to-end histogram - scenario 1.

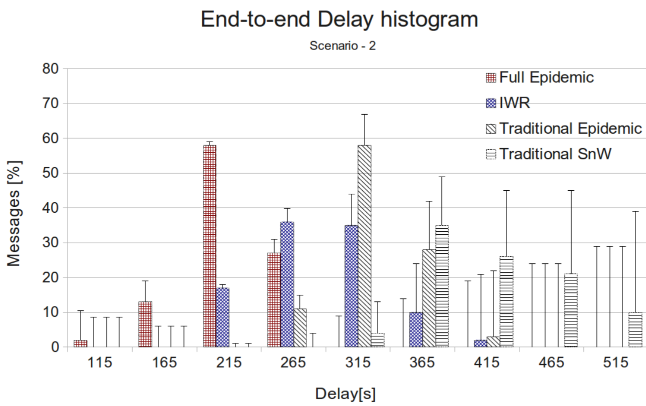

Fig. 4. End-to-end histogram - scenario 2.

duplications; ii) Traditional epidemic routing: without the use of the Internet as a backbone; iii) Traditional DTN SnW routing: without the use of the Internet as a backbone.

Table VI shows the average delivery rate for both scenarios. As expected, the solutions that make use of the Internet as a backbone, namely, Full epidemic and IWR, can deliver more messages compared to both other solutions. No significant increase was observed in delivery rates of the denser scenario, possibly due to higher interference present in the link layer.

The histogram for end-to-end delay in the sparse and dense network scenarios is presented in figures 3 and 4, respectively. The Full epidemic solution delivers faster than all the other solutions in both scenarios. The IWR and the Traditional epidemic solutions can deliver the same number of messages almost in the same period of time. An interesting observation concerning these two solutions shows that in the dense scenario IWR delivers 42 seconds on average faster than Traditional epidemic routing, while in the sparse scenario Traditional epidemic routing delivers 3 seconds on average faster than IWR solution. Thus, the strategy of utilizing the Internet as a backbone is even more efficient when the network density is increased, reducing the overall IWR end-to-end delay. As expected, the Traditional SnW takes longer to deliver its messages in both scenarios.

In delay tolerant systems, the overhead can be measured by the amount of unnecessarily replicated messages, as depicted

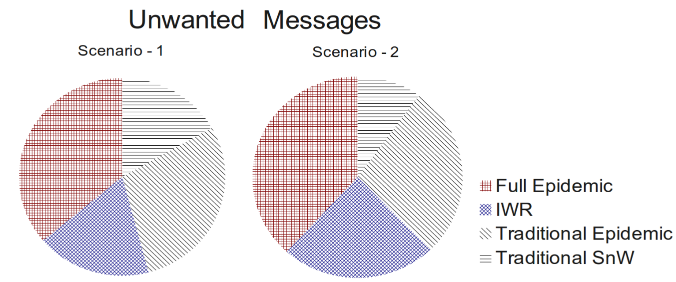

Fig. 5. Network Overhead - Unwanted Messages.

Unwanted Messages				
	F. Epidemic	IWR	Tr. Epidemic	Tr. SnW
Scenario-1	36.14%	17.97%	29.13%	16.74%
Scenario-2	38.28%	23.93%	27.82%	9.94%

TABLE VI
NETWORK OVERHEAD - UNWANTED MESSAGES.

in figure 5. In the simulation, unwanted messages were the messages that arrived late to the destination; plus, the messages that were too old to be stored by a custodian node during a contact, due to buffer full/flooding. IWR is able to overload almost 50 percent less than both epidemic solutions, keeping the delivery rate up within a tolerable end-to-end delay.

VI. CONCLUSIONS

This paper proposes the Intelligent Wireless Router (IWR) protocol for the fixed nodes (home wireless routers) of a cooperative IEEE 802.11 community network. This algorithm selects the best fixed node (agent) to initiate an *epidemy* among the mobile nodes (laptops and smart phones). The IWR algorithm proposes the use of Artificial Intelligence tools (Time Ontology in OWL and KQML) to improve DTN routing in a urban scenario.

Energy consumption (battery life) is crucial for pedestrian nodes in IEEE 802.11 urban environments and routing solutions that produce low overhead are extremely important. Simulation results on realistic urban mobility models show that IWR can deliver almost the same number of messages as the Full epidemic solution, within a similar end-to-end delay when compared to the Traditional epidemic solution causing half of the network overhead. IWR's proposed network scenario, where the user's wired subscribed Internet connection is used as a backbone, is by design, fundamental.

The future tasks to improve this work are: i) simulate the proposed environment with the real world geographic position of the agents. This can be achieved by importing the home wireless routers geographical coordinates in the Omnet++ network simulator and the use of real mobility traces; ii) investigate the possible use of knowledge representation formalisms to represent node's mobility patterns.

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