Sociability Based Routing for Environmental Opportunistic Networks

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***Abstract*—Network opportunism in wireless systems aims at jointly exploiting the resources of separate networks. So far, small emphasis to this paradigm has been given in the literature related to Wireless Sensor Networks (WSNs). This paper first describes a vision on the evolution of WSNs towards the application of this concept. Then, a way to allow exchange of information related to the available resources among networks, is formalised. Finally, the concept is exemplified by considering a specific type of application scenario and resource sharing approach: a vehicular network where pairs of mobile nodes exchange packets by exploiting a store-carry-forward mechanism. This scenario allows the introduction of the concept of Sociability Based Routing.**

I. Introduction

Network opportunism in wireless systems is a recent concept, aiming at jointly exploiting the resources of separate networks according to the needs of specific application tasks [1]. So far, emergency scenarios, and Delay Tolerant Networks (DTNs) based on MANETs (Mobile Ad Hoc Networks), have been mainly discussed in the context of Opportunistic Networks (ONs) [2], [3], with small emphasis on the role of Wireless Sensor Networks (WSNs).

This paper first describes a vision on the evolution of WSNs towards the Internet of the Environment, discussing the concept of network opportunism in WSNs (Environmental Opportunistic Networks, EONs). Then, the paper provides a first attempt to formalise a way to allow exchange of information related to the available resources among network nodes, and networks (either WSNs or of other type), a feature necessary to the development of the paradigm of ONs. Finally, the concepts are exemplified by considering a specific type of application scenario and resource sharing approach, which in the past few years attracted the attention of researchers in the area of DTNs: a vehicular network where pairs of mobile nodes exchange packets by exploiting a store-carry-forward mechanism. This scenario allows the introduction of the concept of Sociability Based Routing, which is discussed in this paper. This routing strategy selects a subset of optimal forwarders among all the nodes and relies on them for an efficient delivery [5], [6].

II. Evolution of WSNs towards the Internet of the Environment

Wireless Sensor Networks (WSNs) are composed of nodes able to cooperatively sense the environment, and possibly control it through actuation devices [4]. Different tasks can be accomplished by a WSN, depending on application needs and the type of physical entities measured/controlled. Future WSNs will be designed so that different application types will be able to run over the same network. Sensing and actuation are respectively the initial and final steps of a process that also involves functionalities like data processing, communication, and possibly storage, data aggregation, etc.

It is expected that in the next few years billions of wireless sensor nodes will be deployed over the globe in various types of environments, with very diverse tasks, hardware, software and communication capabilities. As WSN technologies are becoming more and more evolved, more complex tasks can be accomplished that require convergence of all such functionalities, with their multi-faceted options: nodes can have multiple and diverse sensors/actuators for diverse physical entities to be measured/controlled; communication among nodes can take place by means of separate air interfaces, possibly through infrastructure networks; data processing can require different computing/storage capabilities depending on the type of data to be processed; and so on. On the other hand, to keep the cost of nodes at reasonable levels, they can not be equipped with all such functionalities, at the deepest degree. Therefore, WSNs in the future will be composed of heterogeneous nodes enabling only part of such functionalities, and to diversified extents; each node will be characterised by different resources (sensors, actuation devices, communication, storage and computation capabilities, etc). We denote this new class of heterogeneous WSNs as Differentiated Resource WSNs, to emphasise that the resource types owned by nodes will be the basic feature to differentiate them. As the deployment of WSNs will become increasingly pervasive, evolution towards such class will be a natural fact.

This evolution characterises all types of wireless networks, either environment-related or not, but it will be much more evident for WSNs, owing to the need to keep complexity and cost of devices at minimum levels.

According to the specific task required by the application, the resources available over the network have to be aggregated in order to accomplish the task. So, the network (as a whole) must be equipped with functionalities able to map the availability of resources, and aggregate them in a coherent way, according to application needs. Node mobility, idle/active cyclic states, expiration of nodes, can impact the process of resource mapping, making it more difficult as the network time evolution requires frequent updates.

Suitable methods must be devised to simplify the task of resource mapping, classifying the different types of resources that can be made available and allowing easy exchange of data within network nodes representing the availability of resources.

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Differentiated Resource WSNs will operate in environments where several other (non environment-related) wireless networks will be available, such as GSM/UMTS, WiFi hot spots, etc. If gateways will be deployed, letting networks using different communication standards inter-operate, the separate WSNs will form an heterogeneous Internet of the Environment (different from the Internet of Things, where objects cooperate with no special emphasis to their possible roles as sensing devices) spreading all over the globe (and outside). Gateways will be specifically deployed for this purpose in some cases. However, the use of gateways not specifically deployed to such aim, roaming the environment randomly, will be much more convenient: mobile radio users, while travelling with their mobile phone terminals, laptops, palmtops, connected to infrastructure networks like GSM, UMTS, LTE, etc, will act as gateways connecting the Internet of the Environment to the Internet (of Computers) and the so-called Internet of Things based on ubiquitous computing and radio frequency identification of objects, a concept developed at ITU level.

Every WSN will then be one single component of an heterogeneous aggregation composed of networked objects and sensed environments, with mobile roaming gateways connecting them to the Internet through infrastructure networks.

In this context, the mobile gateways play a fundamental role, permitting connectivity among separate environmental islands. As they are carried by people, the human space becomes central in this architecture. However, it is worthwhile stressing that humans in this context are not (necessarily) the final users, and just become means to let the environment be connected to all other networks. So, this is more a people-centric, rather than human-centric vision: the individuals do not play a role, they are meaningful only as carriers of information.

III. Opportunism in WSNs

In some application scenarios, it might happen that multiple parallel tasks are accomplished by the WSN (for instance, in the case that publish/subscribe paradigms are implemented, and multiple subscribers operate simultaneously). The multiple parallel tasks compete for network resources, and the latter are exploited opportunistically by the single tasks according to their needs, and their (possibly limited) knowledge about resource availability. This is a form of intra-network opportunism.

It might even happen that the resources available in the seed WSN are not sufficient to accomplish the task; in such situation, the network can try to scan the radio environment, detect the presence of other networks deployed for different tasks (e.g. WiFi hot spots, or computer networks in an office environment, or GSM/UMTS public networks) and address such helper networks trying to exploit their available resources. This requires ability to monitor the radio environment to find candidate helpers, and to communicate with them through different air interfaces. This type of ONs is a new paradigm proposed recently by Lilien et al. [1], even if it was not applied by the Author to the specific case of WSNs.

A peculiar type of network opportunism has been recently investigated by some authors, such as Conti et al. [2], [3], where information is routed from source to destination in mobile ad hoc networks (MANETs) through nodes that allow exchange of data even in the absence of a complete path, taking advantage of their mobility that allows interconnection between separate islands of nodes, at the cost of an increased delivery delay. This form of opportunism can be considered as a specific case with respect to Lilien's definition, if mobility itself is considered a resource provided by a separate helper network. This type of ON also represents a sub-class of the DTNs.

If node mobility is considered as one of the functionalities possibly provided by nodes, and as such it is a network resource, then both types of network opportunism can be treated from a formal viewpoint in a coherent way, where a seed WSN exploits resources of helper networks. Section V of this paper exemplifies such situation.

However, the case where the WSN is the seed of this opportunistic process, looking for helper networks according to specific needs, does not represent the most interesting one. In fact, this requires implementation of agents/entities in the WSN able to detect candidate helpers and run decision processes, a requirement that might be difficult to fulfil in some cases owing to the need to keep costs and complexity at reasonable level. A situation where other types of networks, implementing more complex devices, might need the sporadic help of WSNs deployed in the environment, can be more frequent and relevant. In these cases, the seed network (for instance, a MANET or a WLAN) might receive the command to accomplish an urgent task, generated by an unexpected event, and might scan the environment to check whether some help can be found from WSNs deployed in the environment. A sample scenario is reported later.

In all cases, either if the WSN is the seed or the helper of the opportunistic process, the aggregation of different types of networks can be seen under a unified view, classifying node resources according to a common formalism; inclusion of the role played by WSNs, requires consideration of the presence of functionalities as sensing and actuation, and the need to handle very heterogeneous deployments. This paves the way to the new paradigm of Wireless Environmental Opportunistic Networks (EONs), where sensing, communication, data processing and storage, actuation, control, mobility, gateway capabilities are all functionalities (resources) made available by nodes distributed in the environment, with the objective of sensing it, and possibly control it through direct actuation or the interaction with human users.

IV. The Resource Vector for EONs

Let us now try to provide a formalism able to classify the different types of resources that can characterise nodes in a EON.

The aim of this classification is to define a simple method for comparing candidate helpers; it is not a precise definition of the potential help provided, as this would require lots of specific information.

We distinguish the following types of node functionalities that may be useful for the accomplishment of an application task in EONs, and as such can be considered as network resources: Sensing, Communication, Processing, Repository, Decision, Sociability, Gateway, Actuation.

- Sensing (denoted by its initial S in the following) is a multi-faceted functionality, as there might be different types of sensors deployed. Assuming a maximum number N of sensors can be distinguished (for temperature, acceleration, pressure, etc), S for a specific node is a vector of N binary values, where 1 represents presence, and 0 absence of the specific sensing capability.
- Communication (C in the following) is a functionality provided by all nodes of a wireless network. However, nodes can have different communication capabilities. C is measured in Mbitm2/s in the following, putting together the (application level) data rate and the coverage area. To normalise C to one, we consider as reference maximum value 109. Any value for C is represented as compared to the reference value. For instance, C = 0.1 for a node represents a value of 108 Mbitm2/s.
- Processing (P in the following) is a functionality provided by all nodes to very different extents. P is measured in Mips. To normalise P to one, we consider as reference maximum value 103.
- Repository (R in the following) is a value representing the capability of a node to store data. R is measured in MBytes. To normalise R to one, we consider as reference maximum value 103.
- Decision (D in the following) is a value representing the capability of a node to take decisions after the data has been taken from the environment through the sensors. The decision can be taken automatically, providing inputs to actuators, or by interacting with human users through specific interfaces. D is a binary value where 1 represents presence, and 0 absence of the capability to tale decisions.
- SociaBility (B in the following) is a time-varying scalar parameter that has to do with the frequency and type of nodes encounters over a certain time window (see Section V).
- Gateway (G in the following) represents the ability of a node to act as gateway towards other networks using separate air interfaces. Assuming the presence of K separate networks, G is a vector of K binary values, where 1 represents presence, and 0 absence of the specific capability to act as gateway. One value is set to 1 as default, the one representing the air interface used within the network;
- Actuation (A in the following) is a multi-faceted functionality, as there might be different types of actuators deployed. Assuming a maximum number I of actuator types, A for a specific node is a vector of I binary values, where 1 represents presence, and 0 absence of the specific actuation capability.

Given this formalism, every node in an EON can be represented by a vector of size N + K + I + 5. Such vector, denoted as Resource Vector in the following, is mostly static and represents the set of resources made available by the node. The Resource Vector needs to be exchanged with other nodes.

The potential resources of a sub-network of an EON can be measured through a Network Resource Vector given by the sum of the Resource Vectors of all participating nodes. This Network Resource Vector is a concise element that can be published by (some) nodes of a wireless network, either WSN or of any other type (cellular, etc), to easy the implementation of the paradigm of EONs. Through the detection of nodes publishing the Network Resource Vector, a seed network can decide whether a candidate helper is suitable, according to the needs of the specific task to be accomplished. Suitable comparison between the Network Resource Vector of the candidate helpers and of the seed network, can provide indication of which resources are available overall, and what should be selected opportunistically.

Now, the problem is how to aggregate in a simple way the information coming from several nodes in a sub-network, to generate the elements of the Network Resource Vector. Clearly, some resource types (like processing) do not sum up, since the overhead to synchronise the sub-tasks among the various nodes is such that the overall resource (obtained gathering the resources from the different nodes) is smaller than the sum. In other cases, the opposite is true. In particular, Sociability is a property which is depends in a very complex way by the interaction between moving nodes. Therefore, this is one of the elements of the Resource Vector which are more complex to define and handle in a aggregate way. This will be further elaborated and exemplified in Section V.

V. Sociability Based Routing in a EON Scenario

In the present section we aim at considering a specific scenario where mobile nodes take forwarding decisions based on the Sociability parameter (B) of the resource vector, resulting in *Sociable Routing*, a novel routing scheme for ONs. Although illustrative, this is not meant to be exhaustive of the potential benefit of using the Resource Vector in EONs.

The key idea of Sociable Routing is to solve the routing problem in DTNs [5] by assigning to each network node a time-varying scalar parameter depending on its social behavior, called *sociability indicator*, that has to do with the frequency and type of node's encounters. Then, each node forwards its data packets only to the most sociable nodes. Thus, the chances of reaching the intended endpoint are maximized and the amount of transmissions kept under control. There are some analogies between this approach and the game theoretic concept of player's reputation adopted to model security in wireless networks [7].

After giving a detailed formalization of the sociability concept, we simulate packet transmissions in a DTN in an urban context. In particular, we consider a case study where nodes are vehicles moving according to real traffic traces [8].

A. Sociability Concept

The basic idea is that nodes having a high degree of sociability (i.e., frequently encounter many different nodes) are good candidate forwarders. Applying this simple rule to a delay tolerant network is quite straightforward. As first step, one needs to observe nodes behavior and learn their habits.

Then, a synthetic scalar parameter shall be assigned to each node depending on its social behavior. Finally, routing from a source to a destination node is performed by forwarding packets to a restricted set of relays which show a high degree of sociability and, thus, are very likely to get in touch with all possible endpoints.

One further assumption that we need is the periodicity of behaviors, meaning that it is possible to make predictions on the social conduct of a node based on what has been observed before. Roughly speaking, we expect those nodes that showed very high sociability over a time period of a certain length to behave accordingly in the future for a period of at least the same length. This is a reasonable hypothesis in population networks, and we believe it still is in all scenarios where the mobility of nodes is governed by human behavior, as in vehicular networks, pedestrian networks, etc…

1) Modeling: The way in which the social features are modeled should be very simple, on the one hand, in order for the nodes to produce and exchange such information in an inexpensive manner. On the other hand, the challenge stands in capturing as much as possible of the exploitable information in a single parameter, that we shall call *sociability indicator*.

One way sociability could be quantified is by looking at the intercontact information of each node [9]. In particular, the intercontact time analysis reveals how frequently a node meets with one another. As an example, an indication on the average intercontact time of a node with any other could give a rough idea of its social behavior. However, in the latter case, one can appear very sociable by having frequent meetings with a very restricted set of neighbors. Unfortunately, this does not make it a good candidate forwarder.

Moreover, an important aspect to be captured in analogy with human relationships, is that one person who only meets a single friend, the latter being very sociable, can itself be considered sociable. Turning to an information network perspective, a node being isolated most of the time with very sporadic links to a single neighbor, may appear very unsociable. Nonetheless, if the neighbor is very sociable and can reach many destinations, then the former node may also have chances to send its packets to many destinations through a 2-hop path. As a consequence, the presence of sociable neighbors is an important addendum that should be incorporated into the sociability indicator of one node.

Intuitively, it is a natural assumption that mobility patterns of nodes are related to their social behavior. In fact, if a node visits a great number of different locations in a short time, it is likely to meet many others. Although this is true to some extent, there are plenty of scenarios where the concentration of users is not constant in space (e.g., the union of a city center with its suburbs). Hence, the mere covering large distances does not necessarily result in high forwarding opportunities. For this reason, in order to maintain the overall idea detached to any specific environment, we chose not to include any direct information regarding mobility patterns in the sociability indicator.

In [11], the Authors state that two people having similar mobility patterns (in terms of frequency of visits to specific locations) are more likely to meet each other, thus to be able to communicate. Then, they recognize that the main limitation of the previous statement is that even though two people visit the same locations, they do not necessarily do it synchronously. Thus, two such nodes may never be in the range of each other. This is not a rare event, especially at urban scale. Consider for example a public transportation fleet (e.g., buses). Two buses running on the same route have the exact same mobility patterns. However, if one follows the other few kilometers behind, they never reach each other. More generally, there are places like, e.g., a big mall, that many people periodically visit at different time. This results in some similarity of their patterns which does not necessarily reflect meeting opportunities.

Finally, we emphasize that the sociability indicator only highlights what are the best forwarders in a given time period, in the sense of those having the highest degree of sociability. As a consequence, this information is not related to a specific destination to be reached but it is instead absolute. This descends from avoiding a sociability characterization based on mobility patterns and is consistent with the intent of minimizing the exchange of data. This also implies that no prior knowledge of the destination (e.g., its position, sociability indicator, etc…) is requested at the source.

2) Acquisition: Since we do not use information on positions, nodes are not requested to adopt any positioning technique, nor do they have to learn their mobility patterns as in [11]. The two main issues arising with the use of Sociable Routing are i) how a node learns its own social behavior and ii) how it communicates its social behavior to other nodes.

Note that the two issue are strictly connected, as a node needs to know the social behavior of its neighbors in order to derive its own. For this reason, a distributed strategy where nodes, upon encounters, update their own sociability parameter through the exchange of a minimum amount of data, could be the optimum. For example, the sociability updates could be appended to data bundles in order not to overwhelm the network with signaling information. However, this is not addressed here, since our aim is primarily that of presenting and validating the general idea at the base of Sociable Routing.

Hence, in the following we assume that nodes have knowledge of their social behavior referred to a specific time window. In a practical setting, this is equivalent to assuming that: i) a node keeps track of the contacts with its immediate neighbors; ii) it sends this information to a central processing unit (which could be a node itself) that combines it with that of all the other nodes; iii) the central processing unit broadcasts a vector containing the updated sociability indicators.

3) Usage: As previously mentioned, the basic idea is to select a set of sociable nodes that can potentially reach any endpoint. This set should be kept small enough to avoid useless transmissions. To this end, the following strategy can be adopted. A node takes its routing decision at a given time t by i) evaluating the sociability indicators of the current neighbors; ii) comparing them to its own sociability indicator and iii) choosing as forwarders a maximum of N_f nodes that have greater sociability than its. This simple scheme allows to limit the number of bundle transmissions at each encounter by setting a maximum, N_f. Moreover, a node does not transmit any bundle if it does not meet any more sociable node. As a further implication, when a bundle is generated by a node with low sociability degree, a large number of transmissions are permitted, since the source will certainly meet more sociable nodes. On the contrary, if the bundle is generated by the most sociable node, there will not be any transmission until the source is itself in the range of the destination, since it is also the best possible forwarder. This seeming imbalance is explainable as follows. Because an unsociable source is likely to remain isolated for a long time, it makes sense for the network to put a greater effort to route its message along by generating replicas. In the opposite case, when a source is highly sociable, only few transmissions are required because mobility will do the rest.

In a formal tone, by using a notation similar to that of [11], let U be the set of all nodes and $N = |U|$ their number. The sociability indicator of a node $k \in U$ at time t is $s_k(t) \in [0, 1]$. Assume also that at time t node k has a number of active direct links to some neighbors. Let us denote as $W_k(t) \subseteq U$ the neighborhood of k. The routing decision of k consists of either keeping the bundle or selecting up to N_f next forwarders belonging to $W_k(t)$. With respect to a destination node, b, this can be performed by using a decision algorithm to be applied to the set $W_k(t)$ and b, and yields the set, $R_k(t) \subseteq W_k(t) \subseteq U$, $|R_k(t)| \leq N_f$, of next forwarders. The pseudocode is given in Algorithm 1.

Algorithm 1 Routing decision algorithm

$R_k(t) := \emptyset$
if $b \in W_k(t)$ **then**
    $R_k(t) = \{b\}$
else
    $i = 1$
    while $W_k(t) \neq \emptyset \cap i \leq N_f$ **do**
        $h := \arg\max_{j \in W_k(t)} s_j$
        $W_k(t) \leftarrow W_k(t) \setminus \{h\}$
        if $s_j > s_k$ **then**
            $R_k(t) \leftarrow R_k(t) \cap \{h\}$
        end if
        $i \leftarrow i + 1$
    end while
end if

B. Simulation results

In the present section we introduce the simulator that allows us to test the forwarding scheme proposed and to compare it to other existing protocols.

1) Methodology: We have designed an autonomous network simulator for testing the routing scheme. It takes as input a mobility trace and generates mobile nodes accordingly. The time is discretized and resolution is 1 sec. Each node has an infinite buffer for storing the exchanged packets. In a realistic setup, a routing protocol should be evaluated by accounting for limited buffering capabilities. Nonetheless, although we do not address it here, we assess the validity of protocols by also counting the amount of extra packets generated, as a rough measure of resources consumption at network level.

In addition, we make very simple assumptions at physical and MAC layers, namely, nodes are in contact when their distance is less than the transmission range, TR; channels are interference-free; and transmissions are instantaneous. Furthermore, although a node is not aware of its absolute geographical position, it has a complete knowledge of its logical connectivity, (i.e., what other nodes are within its transmission range), and it is always willing to cooperate with others.

A simulation run starts when two nodes are randomly selected as source and destination of a bundle, respectively, and terminates when the bundle is either successfully received by the recipient or discarded for exceeding a timeout threshold.

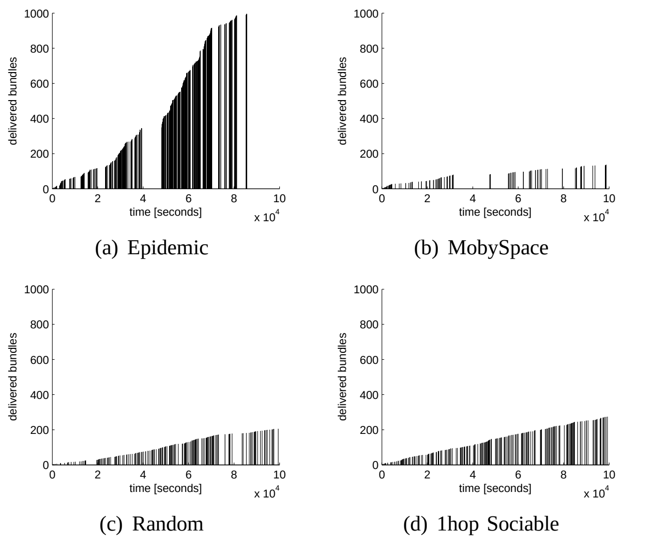
2) Input mobility and parameters: As input mobility, we consider the taxi cab traces available in [8]. It must be noted that taxi cab's movements are not particularly predictable as can be those of a private citizen or even a public transportation vehicle (e.g., a bus). In fact, apart from the most frequent routes (e.g., airport to train station), each time a passenger is collected, a destination which potentially differs from the previous one has to be reached. For this reason, if we can appreciate any benefit from the Sociable Routing scheme in this scenario, we expect even better performance when using, e.g., Seattle city bus traces [10] as input mobility. However, this comparison is left for future work.

We put two constraints in order to speed up the simulations. First, source and destination nodes are randomly picked among those that are located, at the generation instant, in a 10 x 10 km square centered in downtown San Francisco. This indeed decreases the average delivering time by avoiding too far away source-destination pairs. Secondly, nodes that have not been moving for more than 1 hour cannot be source candidates. This avoids extra delays due to when a packet is generated by a cab that is not in service, and thus has greater chances to remain isolated for long.

The number of nodes, all included, is then 535 and the traces are two weeks long. Every simulation is composed of 1000 runs (i.e., 1000 bundles are either succesfully received or dropped due to excess delay) and is started at a random time on the first day of traced period. We set a timeout of 1 day and a transmission range $TR = 500$ meters. This value is in accordance, for example, with the standard IEEE 802.11p [12], which is meant to be employed in vehicular networks. Finally, in case of multiple contemporaneous encounters, one node is allowed to forward the bundle to only $N_f = 1$ neighbor.

3) Results: The performance of our routing scheme, Sociable Routing, is compared against that of other known protocols, namely, Epidemic [13], MobySpace [11] and Random. In the latter, packets are forwarded independently of nodes degrees of sociability.

When simulating Sociable Routing, the time interval between two refreshes of the sociability indicators must be set. This should be calibrated based on the nature of mobility traces. We assume no a-priori information is available about the social behavior of the nodes. We then take $T = 1000$ sec as initial guess.



(a) Epidemic (b) MobySpace

(c) Random (d) 1hop Sociable

Fig. 1. Cumulative bundles delivery over time for the routing scheme considered.

In Fig. 1, we report the cumulative distribution of delivered bundles over time, for Sociable Routing, as well as for the benchmarking protocols. By observing a time window of approximately 1 day, it clearly appears how Epidemic delivers a much larger amount of bundles compared to other solutions. However, as previously noted, this scheme is practically unfeasible.

Conversely, MobySpace is the one delivering the smallest amount of packets. The reason seems to be the presence of large deviations from the mean delay, occurring when a node does not find a suitable relay and keeps the bundle for long. A deeper consideration is that the basic assumption of the protocol, according to which two nodes having similar patterns are likely to meet, is not easily applicable to the case of taxi, where all nodes tend to visit a small set of locations (e.g., airport, main square, etc…) with approximately the same frequencies. Sociable Routing seems to be delivering the largest amount of packets at a fairly constant rate. Random Routing, instead, which employs the same scheme as Sociable but with ”fake” sociability indicators, shows a more irregular trend. The reason is that when packets are sent to not very sociable nodes, they are likely to be stuck, since they do not meet other nodes, and consequently cause extra delays. Finally, all the protocols could deliver 100% of packets before timeout except MobySpace, which dropped 1.8% of packets.

VI. Conclusions

The contribution of this paper has been the proposal of a unified view of network opportunism, which includes WSNs and their evolution towards Environmental Opportunistic Networks (EONs). This new paradigm allows cooperation among nodes belonging to the same network as well as among different networks. All network entities can be informed about the available resources through the exchange of a Resource Vector, which has been formalised.

A practical application of such an approach, Sociable Routing, has also been proposed. Sociable Routing chooses the set of best forwarders among those having high sociability indicators, the latter being time-varying scalar parameters, contained in the Resource Vector. Sociability indicators relate to the social characteristics of network nodes, by capturing the frequency and type of their encounters. The routing strategy has been widely discussed and evaluated by simulation on a DTN of vehicles in urban environment. Results and comparison with other existing protocols showed that sociability based routing can achieve good performance in terms of delay performance and cost.

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