A Pricing Scheme for Porter Based Delivery in Integrated RFID-Sensor Networks

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***Abstract*— RFID-Sensor Networks (RSNs) represent the pervasive components of the heterogeneous Internet of Things (IoT) paradigm. By incorporating both the identification and localization capabilities of Radio Frequency Identification (RFID) and the sensing and inter-communication of Wireless sensor networks (WSNs), RSNs are capable of realizing the IoT on a global scale. A pressing hindrance to cost-effectiveness lies in the deployment of high-end relay nodes that potentiate the backbone of the IoT. Paradigms that depend solely on deploying enough readers and relays to maintain network connectivity and coverage, often converge to infeasible costs. In this work we capitalize on pre-existing mobile nodes in the field, dubbed porters, to carry out the relaying task; utilizing their ubiquitous and dense presence and integrating multiple coexisting systems. One of the prominent challenges facing the integration across multiple systems is the trade factor governing their cooperation. That is, what would the porter gain in return for forwarding RSN packets? The pricing scheme governing the operation and trade-off functionality across RSNs is a hindering factor, seldom probed in current literature. In this paper, we introduce a pricing scheme for a delivery framework in RSNs for the IoT paradigm. Our framework incorporates porter nodes with variable mobility, buffering and transfer capacities; connecting relays and base-stations. Our pricing scheme incorporates major factors of impact, most prominently porter and relay density, network load and cost of service delivery. We present a formal model for this framework, elaborated upon with a use case.**

Keywords: IoT; RFIDs; wireless sensor networks; integrated architecture; adaptive pricing; RSNs.

I. INTRODUCTION

The Internet of Things (IoT) will have a tremendous effect on domestic, entertainment and professional aspects of everyday life. Most notably by promising to provide identity, tracking and communication abilities to virtually every object on the planet [1]. IoT will revolutionize networking over a myriad of applications including Assisted Living Facilities (ALFs), enhanced learning, e-health and automotive applications. Similarly, IoT influence will reform numerous business disciplines such as intelligent manufacturing, retail, supply chain and product lifecycle management, in addition to reliable and safe transportation of people and goods [2].

IoT was initially inspired by developments in Radio Frequency Identification (RFID); pursuing possibilities of retrieving information about tagged objects by browsing an internet address or database entry that corresponds to a particular RFID [3]. However, as IoT grew to represent a futuristic vision of a connected global network of things, the potentials of such a vision included autonomous physical and virtual objects augmented with sensing, processing, and reporting capabilities that exceed the simple identification capacities of RFID systems. Henceforth, the introduction of other technologies and their integration with RFID under the umbrella of a heterogeneous architectural model is inevitable to attain the full roles of IoT.

It is widely accepted that Wireless Sensor Networks (WSNs) represent the most prominent technology to produce the backbone of IoT along with RFID, forming what is known as RFID-Sensor Networks (RSNs) [4]. WSNs are employed in environment monitoring, biomedical observation, surveillance and security, among a multitude of domains. Sensor nodes often connect to base-stations (sink) via relay nodes, for boosting their communication range, since their capped energy mostly would not support long range communication.

The integration of RFIDs and WSNs will increase their combined detection and reporting capabilities. RFIDs extend the ability of a WSN by providing sensible property to otherwise un-sensible objects. Integration with RFID equips sensor nodes with tag IDs that are more suitable for item detecting and data storage and retrieval than MAC addresses are. WSNs, on the other hand, being able to monitor physical events, can provide more information on the measurement of temperature, humidity, pressure, etc., than simple RFID.

Moreover, in an RFID system, reader-tag communication is conducted in single hops without inter-communication among tags. Alternatively, common WSNs features include multi-hop communication, cooperative applications and events triggered inside the network. Furthermore, integrated RSN solutions help reducing unnecessary costs by supporting backup solutions in case of undesired circumstances. For instance, perishable goods can be monitored so that in case they are not preserved properly their transport can be terminated, thus avoiding unnecessary additional transport costs. Table 1 lists the main features of WSNs and RFID systems that, when combined, form the merits of RSNs.

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Consequently, the IoT vision is driven by developments in intelligent mobile devices, which can be part of numerous products, gadgets and vehicle-parts. These devices close the gap between the real word and its virtual representation via, for example, seamless identification and integration with other wirelessly-embedded devices and their surroundings.

Nevertheless, many challenges face this integration-based vision. Inherited heterogeneity, particularly in RSNs, imposes the need for deploying readers and relays that are usually expensive. The span of the IoT network elevates this cost and further makes it infeasible to adopt a full-scale deployment scheme of these expensive components. Yet, transmission over long distances represents another dimension of these relay-deployment challenges. A major hindrance to the deployment of large scale IoT systems rises from the elevated costs of deploying reliable and connected components. That is, ensuring that all IoT components interplay in a stable topology is non-trivial, and most importantly costly. Ensuring the end-to-end links between all major source-destination pairs is a cumbersome requirement.

In remedy, our approach capitalizes on the pervasiveness of mobile devices, and movable entities, with store-and-forward capacities (e.g. vehicle, cell phone, etc.). Accordingly, a data packet could be handed over to the "porter" node as long as the destination would be reachable along its movement trajectory.

The important question arising here is merely the incentive. Why would a mobile node act as a porter and carry-forward a given data packet? In this work we present a dynamic model for pricing the task of the porter, and setting a utility function that the porter and other nodes could use to determine if it is cost effective to utilize a porter to handle data-forwarding. In this function, we build upon two major measures of efficiency, load balancing across porters and minimizing total cost from source to destination. To this end, we list our contributions in this paper as follows:

- We introduce an RSN architecture that integrates RFID and WSN components on two levels by including: a) RFID Reader/Relay (RR) nodes b) Sensor/Tag (ST) nodes.
- This architecture adopts a porter-based delivery approach that utilizes the mobility of Porter Nodes (PNs) to connect RRs to the base-stations in the network.
- Finally, we provide a pricing scheme for porter-based delivery in the proposed RSN architecture.

The rest of this paper will be organized as follows. Section II will elaborate on related work in integrated IoT frameworks, and the pricing issues arising in realizing it. Our system model is presented in Section III, detailing the network and pricing models realizing our RSN framework for the IoT. We present a detailed analysis of our performance metrics, and benchmark it with current approaches, in Section IV. Finally, Section V presents our conclusions and future directions in this domain.

II. BACKGROUND AND RELATED WORK

The realm of IoT has witnessed growth in many fields. As its main enablers, both WSN and RFID research have boomed

TABLE I. A COMPARISON BETWEEN WSNS AND RFID SYSTEMS

	WSNs	***RFIDs***	***RSNs***
Purpose	Sense physical events in the environment in addition to processing and inter-communicating	Identify and locate tagged objects	Integrates both capabilities
System Components	Sensor node, relay node, base-station	Tags, readers	Sensor/tags, readers, base-station and courier nodes
Communication style	Multiple-hop	Single-hop	Require both relays and readers to support multi-sink nature
Power	Active with on-chip battery	Active, passive or semi-passive	Active, using WSN battery and harvested power
Communication range	Dependent on Transceiver properties, typically 10's to 100's of meters	Few centimeters to few meters	Capped by that of RFID readers and/or WSN relays
Addressing	MAC dependent, most recently IPv6 enabled	Tag ID	Supports a dual tag ID/MAC addressing system
Protocols	ZigBee, WiFi, Bluetooth	RFID standard	Under provisioning
Mobility	Usually static	Move with attached object	Highly mobile
Size	Medium to small sensors	Very small tags	Varies according to integration purpose
Cost	Sensor node: cheap Relay node: expensive	Tag: very cheap Reader: expensive	Couriers are not deployed- paid per use Sensors/tags: cheap
Deployment	Random or deterministic	Mostly fixed	Adapts to porter trajectory

in terms of energy efficiency and sustained coverage. However, the multitude of domains relating to IoT and RSN research has generated a significant redundancy in terminology. In fact, many observations currently rendered under IoT have in fact been previously noted in predecessor systems. In this section we highlight both the background and interleaving domains that constitute RSNs.

A. Integrated RSN architectures

A wide variety of RSN architectures have been proposed in the literature [6]-[16]. As aforementioned, the main purpose of integration is to widen the operational and functional capacities of the resulting systems. Yet, RSN integration is continuously challenged by the heterogeneity among the technologies and their corresponding protocols. From an architectural perspective, we classify RSNs into three types: a) sensor-tag (ST) b) sensor-reader (SR) and c) reader-relay (RR) integrated architectures There is, however, a fourth mixed integration approach that does not involve any architectural design where a mix of RFID and WSN components exist separately in the network [8].

As for the ST architecture, the approach incorporates either providing RFID tags with sensing capabilities by equipping tags with sensory circuitry while restricting their communication to readers, or integrating tags with wireless sensor devices such that the integrated tags are able to communicate with other wireless devices in addition to readers. Nevertheless, the applications related to ST integration vary according to the type of tags involved. For instance, a passive RFID tag integrated with temperature and photo sensors is introduced in [9]. The tag gathers power from external RF signals and senses ambient temperature and light as well. It enters a ready state when it receives a powering RF signal which activates its internal clock generator. The tag enters an interrogating state upon receiving a request from the system's base-station.

Accordingly, the demodulator and decoder are activated to enable the sensors taking the tag into the active state and requested data is transmitted to the base-station. *ThermAssureRF* [10], on the other hand, deploys semi-passive tags to monitor temperature fluctuations over time during shipping temperature-sensitive goods. The integrated tag is credit-card size and able to record both temperature and location information. The application is also capable of receiving programmable thresholds through the software application. It can be used for tracking inventory throughout the entire facility.

In [11], multiple sensors with different functions are embedded in an active RFID tag. These active ST nodes are controlled by a programmable timer. The sensors sample external data independently and periodically. The obtained raw data are preliminarily processed by the microprocessor before sending to a more powerful database via the reader. The database integrates the data from the reader and from other sources such as user interventions and the Internet. Once the remaining energy of the tags is less than a particular unworkable level, the tags are able to automatically switch to passive mode. This means that the sensing function operates only when the tag is in the interrogative zone of the reader.

A wireless smart sensor platform is presented in [12]. It uses RF links, such as WiFi, Bluetooth, in addition to RFID signals to communicate in a point-to-point fashion. The platform consists of a collection of sensors and actuators. Each sensor or actuator is equipped with a Smart Sensor Interface (SSI) to extract data from sensors, send commands to the actuators, and provide a communication interface to some central control unit.

As for the second class of integration architectures (i.e. SR), this integration enables new functionalities and leads a number of new applications. The integrated RFID readers are able to sense environmental conditions, communicate with each other in wireless fashion, read identification numbers from tagged objects and effectively transmit this information to the base-station. SR architecture could be done so that RFID readers are integrated with wireless devices for the sake of wireless communication in WiFi standards. For example, the integration of RFID into Ad Hoc networks to collect data from RFID tags deployed over a large area has been studied in [13].

The basic idea of integration is to connect the RFID reader to a transceiver which has routing capabilities and can forward information to and from other readers. Via multi-hop communication, such integrated readers can read tags from a distance that is well beyond that of the normal range. In addition, RFID readers and sensors are combined with multifunctional devices, such as PDAs and cell phones. The authors in [14], for instance, provides applications to add sensor networks to RFID readers in wireless devices such as cell phones, PDAs and laptops.

In terms of reader-relay (RR) integrated architectures, a Smart Integrated WSNs and RFIDs (SIWR) was proposed in [15]. This is a two-layered hierarchical architecture where upper layer consists of integrated Super Nodes (SNs) conducting the roles of RFID readers and wireless relays, simultaneously. The lower layer is formed of Light Nodes (LNs) which are either sensor nodes or tags. The SIWR architecture aims toward dominating the cost factor by distributing the sensing and relaying loads over the components of integrated networks in an optimum fashion. This approach is unique because it does not overwhelm the light sensor and tag nodes (LNs) with relaying tasks but rather focuses on the optimal distribution of the most costly reading/relaying components. Table I contrasts these three paradigms.

The architecture presented by SIWR was further expanded in a delay-tolerant framework [16] that better addresses IoT nature and delivery concerns. Here, a third tier of nodes, called Courier Nodes (CNs), is introduced as connectors between SNs and the base-stations. The description of CNs stems from the diversity of mobile wireless devices and gadgets in a given IoT topology. Such devices enjoy variable levels of buffering, mobility and transmission capabilities that allow each of them to participate in the overall delivery effort of the system.

The RSN architecture we adopt for our pricing scheme in this paper applies RFID-WSN integration on two levels. First, it assumes the existence of tags and sensors either separately or according to one of the aforementioned ST approaches [9]-[12]. Second, it applies the RR concept [15],[16] assuming the existence of nodes undertaking both tasks of wireless relying and RFID tag-reading. In addition, our architecture embraces the concept of CNs as genuine components of any IoT layout and parts of its routing/delivery scheme. Figure 1 illustrates the main components of this adopted architecture.

B. *Pricing models in heterogeneous networks*

The notion of creating incentive for wireless nodes to take part in a group task has recently gained prominence in the wireless networks literature. A recent study was presented in the domain of mobile wireless networks (MWNs) in [17], where incentives trigger selfish nodes to serve global network goals. As the domain and scale of networks grow, especially in IoT, two major notions surface. The first relates to utilizing ubiquitously available resources; in deploying systems that would depend on already existing systems to meet its functional requirements. Oteafy *et al* presented a dynamic architecture for WSNs where resource sharing is adopted to re-utilize pre-deployed resources [18].

Pricing schemes in heterogeneous networks cover a broad spectrum of factors to determine the value of a resource. In general, the most efficient schemes capitalize on the differential values of each of the constituents. Following the basic laws of supply and demand, the abundance of resources and their homogeneity decrease their value. However, higher prices are usually assigned to nodes with scarce services, or those with elevated QoS measures [19]. Generally, factors such as bandwidth, buffering capacity, residual energy and tendency to assume selfish behavior in the network, all contribute to pricing.

C. *Realizing an IoT framework*

Having both RFID and WSN technologies to operate concurrently in an integrated IoT architecture imposes several challenges and requirements. The most obvious refer to the additional costs related to designing and deploying integrated hardware components. These components are naturally more complicated than simple sensors or tags. If a device applies ST integration, for instance, then it is expected to operate both communication protocols either simultaneously or alternatively. This will put an additional operational load on the device which translates into additional processing and energy consumption. Hence, accurate deployment is a critical factor in determining the efficiency of any RSN system [15].

In case of RFID deployment, particularly, redundant readers' deployment is a common practice to guarantee area coverage [20]. Redundancy, however, is not a cost-effective approach. Even when discarding the RR integration option and considering stand-alone readers, redundancy still pose the side effect of creating significant interference among readers and consequently degrading the performance of the whole system. Nonetheless, overlaps among readers' zones represent an inevitable consequence of achieving full coverage.

According to [21], a maximum coverage of 90% of the intended area is achievable without any overlaps. Such a situation requires applying redundancy elimination algorithms to identify and deactivate redundant readers [22]. Reducing overlaps and balancing the load of readers, in addition to reducing the delay and monetary cost of the system, are all considerable constraints for any efficient RFID coverage scheme. Thus, architecture that separate relaying and inter-reader communication from interrogation form a practical realization for a large scale IoT.

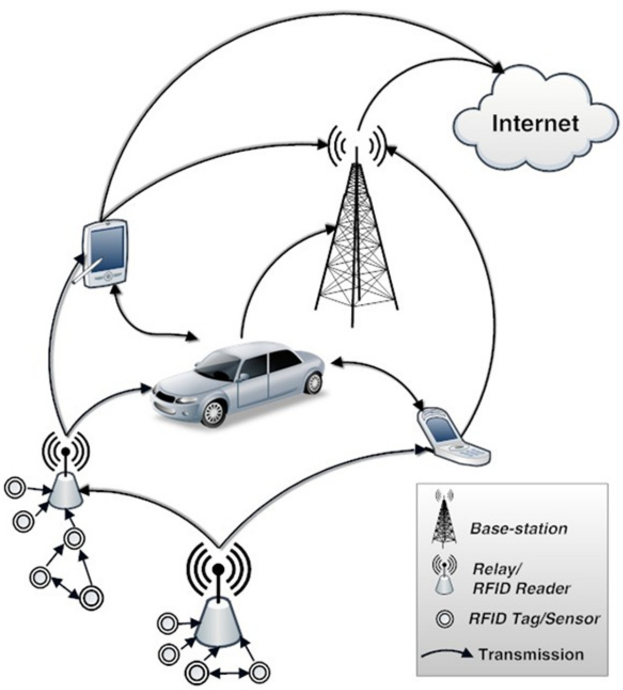

Figure 1 - Porter-based RSN architecture

Additional challenges regarding an efficient IoT framework relate to accurate and reliable communication [23]. Relays are expected to process the received information from tags and sensors reliably and allow the appropriate action to be taken within a short period of time. Reliability and accuracy are also expected for the data transferred by the couriers (porters) delivering data to the required destination with reliability and to provide a confirmation for the successful completion of a task.

The level of reliability and accuracy is dependent on the criticality of the specific application. Moreover, considering the fact that both sensor nodes and active RFID tags present scarce resources, the integrated RSN should take into account this limitation. The integrated system should be energy efficient to make sure that accurate and reliable communication will be achieved with the minimum possible energy consumption.

The framework presented in [16] was targeting IoT requirements over several aspects. First, it adopts a deployment scheme that specifies the optimum number and placement for RR nodes including the readers which, in turn, minimizes collision and dominates the cost factor. Second, It address delay-tolerance constraints via an ILP-based solution that selects the best set of couriers (porters) that guarantee minimum delay between a given pair of RRs and base-stations.

Lastly, the framework is designed to make use of ubiquitous nodes ambiently present in the IoT realm utilizing their abundant collective resources to serve the connectivity of the integrated components. These architectural characteristics will be further clarified when describing our system models.

III. SYSTEM MODELS

In this section we detail our framework's network, pricing and communication models. All three models were designed to tackle challenges of RSN applications under IoT. Most importantly, the interplay of heterogeneous nodes in the architecture present inherent complexity. Thus, the models have been devised to cater for heterogeneity while alienating highly variable factors that would deem this model infeasible/intractable. In all cases, the underlying assumptions are clearly stated in the respective models.

A. Integrated RSN architecture (Network model)

We adopt a three-layered hierarchical architecture that maximizes the integrated network usability in two dimensions.

- The upper layer consists of integrated Reader/Relay (RR) nodes which communicate periodically with base-stations to deliver the data being collected at the lower layer. RRs are assumed to consist of RFID readers and advanced processing and communication units to aggregate sensed data and coordinate medium access, in addition to relaying data to the base-stations. This approach was originally proposed in [15] and [16] to dominate the cost factor by distributing the sensing and relaying loads over the components of integrated networks in an optimum fashion.
- The lower layer of our architecture consists of simple sensors and tags that either exist separately or integrated/jointly on the same device (ST). These nodes are fully dedicated to performing sensing operations and are absolutely relieved from conducting any relaying or processing, which in return prolongs their operational lives. ST nodes are relatively cheaper to deploy and have a minor impact on network cost. Accepting integrated ST nodes opens our architecture to a wider variety of IoT applications that requires such versatile and more capable nodes.
- Finally, the middle layer of our architecture is made of Porter Nodes (PNs). These encompass every-day entities and devices comprising the objects in an IoT. Such nodes include smart phones, mobile devices and vehicles equipped with transceivers. They vary in their buffering capabilities, processing and bandwidth, but they all exist abundantly in an IoT setting. Thus, they represent an excellent choice as linkers between RR nodes and base-stations if and when disconnection occurs between these two tiers. A PN is potentially moving towards or residing within the communication range of a base-station is of utmost concern; and fits the insight of this work. PNs buffer the data until a suitable "best next hop" is found, conducting a delay-tolerant routing scheme known as Store-Carry-Forward (SCF) [24]. If transmission power permits, a PN may even assume the role of a relay and directly transfer a SN/ST/RR load to a base station.

Figure 1 illustrates the proposed RSN integration architecture. At the lower layer reside integrated ST nodes which follow any of the integration options mentioned in the previous section. Some of these STs are capable of intercommunicating with each other through their sensory components. STs are dedicated to data collection. Their data loads, both singular and aggregated, is gathered by the second integrated level of the architecture: the RRs. The reader component of the RRs enforces these nodes to be efficiently deployed to fully cover the RFID tags in the topology. The relay component, on the other hand, is requested to deliver the data to the base-stations.

However, connectivity to the base-station is not guaranteed and may face with many obstacles (e.g. distance, signal reflection, multi-path, etc.). The PNs represent the third layer of our architecture that is responsible of connecting RRs to the base-stations if necessary. PNs are represented by nodes with variable transceiver (Tx) capabilities which ambiently exist in an IoT setting, including vehicles and smart devices as well be elaborated upon in section III.C.

Formally, we represent all nodes in the network in a single set $\boldsymbol{N}$, whereby each component $\boldsymbol{n_i} \in \boldsymbol{N}$ has T_x capabilities. However, it is imperative to note that nodes are heterogeneous in nature, thus each nodes type, denoted by $\boldsymbol{Type}(\boldsymbol{n_i})$ is defined as:

$$\boldsymbol{Type}(\boldsymbol{n_i}) \in \{\mathbf{ST} \vee \mathbf{SN} \vee \mathbf{T} \vee \mathbf{RR} \vee \mathbf{PN} \vee \mathbf{BS}\} \tag{1}$$

Evidently, the location of each node dictates its neighborhood and thus connectivity parameters. Hence, it is important to define $\boldsymbol{Loc}(\boldsymbol{n_i}) = (x_i\, ,\, y_i)$ representing the relative location of node $\boldsymbol{n_i}$ to the deployment region. However, it is important to note that in reality accurate measures of location are not mandated for determining connectivity, in light of the effectiveness of beaconing and signaling protocols that dictate neighboring nodes.

Moreover, since most of the devices in this paradigm are battery powered, it is important to retain an indicator for the residual energy of each node $\boldsymbol{n_i}$ as $Batt(n_i) = (0,100]$. Since heterogeneous nodes inherently possess different power sources, and are equipped with different batteries, the absolute residual energy is not of important reference. Thus, we refer to the percent remaining as an indicator of energy, when compared to the power mandate of any operation the node is asked to carry out. Finally, to establish a metric of connectivity and arbitration (when deciding on a relaying route) it is important for each node to update its list of neighbors. Thus, each node in the network will store a set of identifiers for the neighbors in its vicinity, such that:

$$\boldsymbol{V}(\boldsymbol{n_i}) = \left\{ \forall \boldsymbol{n_j} \,\middle|\, s.t.\ \boldsymbol{n_i} \text{ and } \boldsymbol{n_j} \text{ are in comm. range} \right\} \tag{2}$$

Noting the hierarchy of the proposed architecture, the task of each RR would be to forward the packets received from sensors and STs to the base station. In doing so, the RR might require the use of a PN, which comes at a cost. Thus, each $RR_j \in N$ will have a monetary purchasing power, denoted as $\$(RR_j)$. The utility of this purchasing power is a major component of the pricing model.

B. Porter nodes

Porter Nodes (PNs) represent the backbone of our integrated RSN approach. Although they do not necessarily run a specific WSN protocol nor belong to the RFID realm. Yet, PNs are solely responsible of providing connectivity between the RRs and their corresponding base-stations which are responsible, in turn, of linking the system to the internet. We assume the following about PNs in our proposed architecture:

- PNs are inexpensive, as they do not require deployment nor maintenance. they are simply utilized for a cost.
- They offer data storage that is sufficient for SCF routing and/or to relay data without the need to buffer.
- They communicate wirelessly. Thus, other devices that have needed resources but do not communicate on one of the accessible mediums in our architecture would not be considered. It is important to note at this stage that the access medium and MAC considerations are beyond the scope of this paper. In future networks, vertical handoffs and high-end devices will encompass a multitude of access schemes, and the barrier of heterogeneous access schemes will eventually be sidelined.

PNs may carry out relaying tasks in return of a monetary value. i.e. they offer relaying as a service. The price of which will be decided upon according to the pricing model explained in Subsection III.C. Figure 2 depicts two scenarios that illustrate the role of porters in a given IoT setting and how their relative pricing is decided upon.

An inherently potentiating feature of PNs is that they are mostly on the move, so their utility is manifested in different areas of need. Actually, areas that usually require higher rate of services (identification and sensing) would already be the areas of higher population of users carrying porter resources (cell phones, vehicles, etc.). Thus, utilizing them in this framework is only intuitive.

Since understanding the trajectory of a PN would highly influence its utility in acting as a SCF entity, it is important to capture the potential neighborhood of each PN. Thus, a set $T(PN_j)$ is constructed for each $PN_j \in N$ according to:

$$T(PN_j) = \{ \forall \boldsymbol{n_i} \mid \exists\, \boldsymbol{n_i} \in \boldsymbol{V}(\boldsymbol{PN_i}) \text{ along } \boldsymbol{PN_i} \text{ trajectory}\} \quad (3)$$

Since this is an important metric, determining the trajectory of potential PNs is critical. However, noting that the domain of mobility management, estimation and tracking is already extensive, determining the trajectory of a PN is beyond the scope of this work. Thus, we will assume that each PN_j will hold knowledge of its trajectory *apriori*, and its respective $\boldsymbol{T(PN_j)}$ is thus constructed.

Finally, since a PN could take on the task of SCF for multiple data packets, each PN_j would determine its maximum load for data buffering and forwarding, and constantly maintain a load parameter $\boldsymbol{L(PN_j)}$. Normalizing each PN's load over its maximal, we determine that $0 < L(PN_j) < 100$, reflecting a sheer percentage.

C. Pricing model

Many factors will affect the usage of ubiquitous devices as porters. One of the deciding factors will be the trade of relaying for a monetary value. The factors affecting the calculation of this monetary value will be detailed in this subsection.

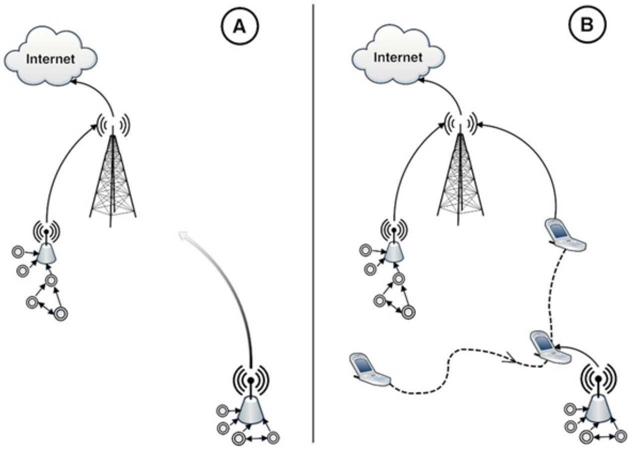

Figure 2 - The role of a porter node. The scenario in (A) renders the sink unreachable by the bottom reader, however in (B) a cell phone acting as a porter would perform SCF.

1) Porter desnity:

As providers, the number of available of porters that could carry out the relaying task has an inversely proportional effect on their price. However, this is only an arbitration factor when all other determining factors are equal.

Given a RR_i with a packet to relay, the density of PNs in its vicinity, denoted as $D_{PN}(RR_i)$, determines the cost associated with recruiting any given $PN_j \in D_{PN}(RR_i)$. Thus, the potential monetary weight of each PN_j is denoted as $\boldsymbol{\alpha_{PN_j}}$ and follows:

$$\boldsymbol{\alpha_{PN_j}} \propto \frac{1}{D_{PN}(RR_i)} \quad (4)$$

Where $\forall\, PN_j \in D_{PN}(RR_i)$, the destination for the packet from RR_i has to be $\in V(PN_j)$, and hence

$$D_{PN}(RR_i) \subseteq V(RR_i). \quad (5)$$

2) Porter load:

If more than one PN can carry the task of SCF, in the vicinity of a given RR_i, then it is important to assign the forwarded packet to PNs with less load. Thus, noting the load factor of each PN, we ensure that:

$$\forall\, PN_k \in V(RR_i): \quad \boldsymbol{\alpha_{PN_k}} \propto \frac{1}{L(PN_k)} \quad (6)$$

3) Distance of transmission/relay:

It is important to note the heterogeneity of potential porter nodes, and their mobility patterns. Thus, the distances of porters for a given RR_i with a packet to forward is mostly unequal. In terms of reducing power consumption, it is most beneficial to offload the packet to the nearest $\boldsymbol{PN_j}$. Thus, we denote the effect of distance on $\boldsymbol{\alpha_{PN_j}}$ as:

$$\boldsymbol{\alpha_{PN_j}} \propto \frac{1}{dist(RR_i, PN_j)} \quad (7)$$

4) Guarantee of delivery:

In many cases, the vicinity of a given RR_i with a packet to forward does not contain a PN which would reach the destination. Hence, connectivity is not guaranteed and the

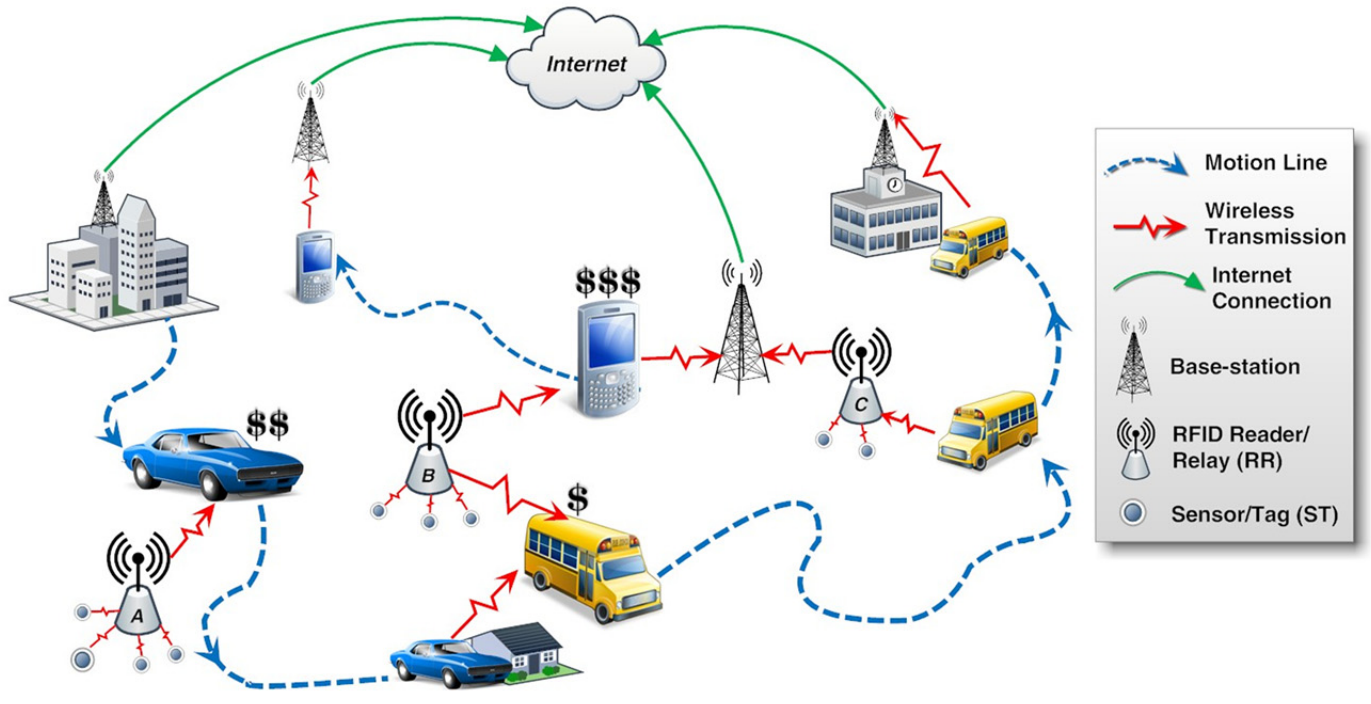

Figure 3 - Several porter-based delivery scenarios for an integrated RSN in an IoT setting

chances of the packet reaching the BS is hence reduced. If the packet is time sensitive, the RR cannot afford to wait for another round for more PNs to arrive. Thus, it is more probable that RR_i would attempt to offload the packet onto the PN with the largest number of neighbors, in hope of reaching the destination via another PN by multi-hop. Accordingly, the weight $\boldsymbol{\gamma_{PN_j}}$ follows:

$$\boldsymbol{\gamma_{PN_j}} \propto \left|V(\boldsymbol{PN_j})\right| \tag{8}$$

Where

$$PN_j \in \{\forall\, PN \in V(RR_i) |\, \nexists PN_k \text{ s.t. } \mathrm{BS} \in V(PN_k)\,\} \tag{9}$$

IV. USE CASE

We will elaborate upon a use case demonstrating the utility of heterogeneous porter nodes in providing connectivity to distant RR nodes. The scenario depicted in Fig. 3 includes three RR nodes *A*, *B* and *C*, each covering a variable number of ST nodes. All the RRs are static and incapable of communicating to any base-station (except for RR *C*) due to distance boundaries. The scenario also assumes three porter nodes: A private car, a school bus and a private smart phone held by a pedestrian.

Evidently, the three PNs are all mobile and on the move, yet their mobility patterns are not as deterministic. I addition, they vary in their buffering, processing and transmission powers. This will have a direct effect on the manner each PN would charge any RR for a delivery request. RR A, for instance, was almost stranded until it sensed the private Camaro approaching. This PN (i.e. the Camaro) may have its destination well defined (i.e. a residence with a specific address). The duration of time it will take it to get there and how much its driver would deviate from the planned road. I other words, delay is highly questionable in the case of this PN which is a critical factor for the RR's discoing to forward its data load or not. Yet again, it is rich in its buffering and communication capabilities. The RR is not sure if an alternative PN would make contact any time soon. The final pricing decision takes all these factors in consideration.

We assume that RR *A* decides to forward its data load to the private Camaro based on an entry in its history table that states its frequent encountering of another PN: the school bus, at a certain window of time five days a week. This particular PN has a more deterministic route and transmission powers equivalent, if not better, than that of a private vehicle. Thus, the price of its service is cheaper than that of the vehicle. Along its rout, the school bus passes by the second RR *B* and receives its data load, as well. Prior to reaching its final destination, the bus encounters a third RR *C* that is able to communicate immediately to a base-station. This encounter, however, is brief and depends on the speed of the bus which is still on the move. Hence, the bus forwards to RR *C* only the least delay-tolerant amongst its data load. The rest of the load carried by the bus may be off-loaded at the base-station situated at its destination.

Finally, there is the third PN: the cell phone, which is carried by a walking person. Under the circumstances, this PN is the most expensive to relay on. It is slow, its mobility pattern is highly random, its buffering capabilities are limited and its communication is already restricted via a service provider. However, this particular PN is distinguished for one feature; its social network that is represented by its address book. Such PNs are highly useful in situations where social routing is being used to deliver data on personal/group bases (i.e. activity groups or task forces) or to inter-route among these groups until a lesser-connected destination is reached. Nevertheless, they are still considered to be more costly to deploy than another types of PNs.

As shown from Figure 3, any device or physical object under the umbrella of IoT may –theoretically- serve as a PN regardless of its capacities. This applies to personal belongings, cellular and smart phones, tablet PCs and lap tops, private vehicles and means of public transportation, public property including traffic signals, mail boxes and light poles. Each of these may be defined as a *thing* in the context of IoT and, if equipped with sufficient buffering and transceiver capabilities, may serve as a PN in our proposed architecture with a cost that is dependent on its residual energy and respective load. Furthermore, depending on social/operational links among these porters, they may form groups or clusters to seamlessly intercommunicate handle larger or more urgent types of data.

V. CONCLUSIONS

Evaluating a framework for the IoT carries many dimensions. Most notably, the cost of deploying and maintaining a network, especially when targeting large scale scenarios, becomes a prominent factor of feasibility. It is important to understand the functional requirements of a network pre-deployment, and the cap on performance of its constituents. In this work we presented a novel model in integration, specifically for the dynamic and large scale of IoT, to integrate sensor/RFID nodes, with capped reader.

The major insight into this work is utilizing heterogeneous nodes, already in the vicinity of the deployed RSN, to augment and boost its functional capabilities. That is, having a dynamic and independent model that would benefit from ubiquitously abundant resources in the field to re-establish and strengthen connectivity when needed. This work presented a pricing scheme for monetary exchange of forwarding (relaying) services rendered buy such devices (dubbed porter nodes). The main factors of efficiency sought are load distribution, energy efficiency and cost reduction for overall operation.

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