# Dynamic Resource Reuse Towards Participatory Sensing Networks

Sharief M.A. Oteafy and Hossam S. Hassanein
School of Computing
Queen's University
Kingston, Ontario, Canada
{ oteafy | hossam }@cs.queensu.ca

***Abstract*— In recent years the demand and density of Wireless Sensor Network (WSN) deployments has generated overwhelming underutilization of resources across multiple deployments. More recently, the proliferation of smartphone usage has augmented sensing architectures with readily available resources to enable data collection in real-time; aiding the adoption of participatory sensing network (PSN) paradigms. Unfortunately both literature domains remain disparate, and their operational mandates dictate significant variance despite their apparent common goals. In this paper we present a formal paradigm for resource representation across ubiquitous platforms, and present dynamic heuristics for utilizing WSNs and participatory-based transient resources towards serving multiple applications in concurrency. The presented paradigm, namely Dynamic Resource Reuse (DRR) WSN, supports multiple owners of resources and incentivizes their collaboration via token-reward systems. We capitalize on dynamic incentive mechanisms to solicit the contribution of resources from WSNs and PSNs. The core contribution of this work lies in operational synergy, facilitating cross-network functional utilization of all readily available resources, despite their network ownership.**

***Keywords*— Participatory Sensing; Sensor Networks; Novel Paradigm; Dynamic Topology; Multi-application Overlay, Heterogeneous architecture**

## I. INTRODUCTION

The evolution of Wireless Sensor Networks (WSNs) and spread of its domains generated great interest in its adoption. In recent years the demand and density of deployments has generated overwhelming underutilization of resources across multiple deployments. The proliferation of smartphones, and their abundance of sensors and wireless access networks, enabled an important dimension of sensing; namely participatory sensing.

In participatory sensing network (PSN) paradigms, users are delegated to either actively or passively contribute to data collection via their (mostly) smartphones [1]. The quality, granularity and context of data collected varies widely. This variation is impacted by the mode of data collection (active/passive) quality of hardware used, detecting user context, commitment of users to following sensing mandates, among other factors.

However, in more orthodox WSNs, there is significant dependency on data quality and context, warranted by the design and deployment phase. Yet, this static design has limited the applicability of WSNs in many scenarios. We hereby note the lack of two factors that hindered dynamicity and true efficiency in deployment and operation (1) visibility and utilization of resources in the vicinity of a given WSN deployment. (2) Capitalizing on resource-rich devices that "pass-by" the region of deployment.

It is important to note the definition of a resource here as a component that possesses functional capabilities, and has the means (e.g., wireless transceivers) to interact with the network. A rigorous definition is presented in Section III. As such, given a distinct identifier for the functional capabilities of each resource, we expand the notion of a resource to encompass those of WSNs and PSNs.

In recent advancements that would potentiate ubiquitous communication, the Digital Living Network Alliance (DLNA) standard is a forerunner [3]. Researchers have devised a standard for communication that is now adopted by smart phones. Accordingly, nearby devices equipped with the DLNA standard would be able to communicate and share resources and data, a precedence to great cooperative operation in future mobile devices.

While each of the aforementioned paradigms strives to deliver functionality to gain market prominence, it is evident that there is no clear winner. That is, WSNs have already been stalled by rigid design mandates and tailored sensing solutions. While PSNs capitalize on a seemingly abundant resource – user smartphones – they still face significant challenges in managing user requirements and commitment, QoS establishment and ensuring serviceability in non-urban environments. There is no single solution that caters for all. Reliable WSNs fail to scale and adapt as PSNs to new functional requirements.

Thus, it is our goal to synergize sensing resources across wirelessly-enabled paradigms, to establish functional sensing networks pre need. The notion of addressing functional requirements need not be assigned pre-deployment. In fact, we aim to offload functional requirements on all available resources, across network platforms.

978-1-4799-3972-5/14/$31.00 ©2014 IEEE

Evidently, the major focus of this work is capitalizing on transient resources in synergy to other static resources. Thus, abstracting the attributes of resources across contributors allows for a homogeneous utilization of all resources, based on utility and cost rather than their providing devices.

Our contributions in this paper are two-fold. (1) We introduce a dynamic architecture that encompasses resources from WSNs and PSNs; named DRR-WSN, and (2) Adopt an incentive scheme that capitalizes on token-based rewards to entice providers to contribute their resources.

The remainder of this paper is organized as follows. Section II highlights the motivation behind this synergy proposal, and relevant background in service oriented WSNs and crowd sensing. The system model and details of DRR-WSN are presented in Section III. Our performance evaluation and results are detailed in Section IV, and conclusions are presented in Section V.

## II. MOTIVATION AND BACKGROUND

This work was motivated by a simple notion. Instead of seeking an exclusive solution to offer reliable and dynamic sensing, we will integrate and synergize the operation of WSNs and PSNs. Thus, our quest translates from deploying resources to reusing the ones already available, across a multiplicity of networks. We build upon earlier work in [4] whereby a rigorous resource abstraction has been presented in light of WSNs and the ensued functional requirements.

### A. *Service oriented WSNs*

The mass of literature on services in wireless and wired networks, with major advancements in telecommunications and web-services, steered a considerable amount of attention towards approaching WSNs as a group of service enablers [7]. Thus, having a pre-defined set of protocols that enable service discovery, authentication and usage charging, these protocols could be adopted in a WSN setting to sustain a given application(s). However, major issues arise in control overhead in probing all these nodes as service providers, and the constant querying and processing entailed. In fact, as WSNs are quite specifically tailored to their design goals, little performance gain would result from migrating to a generic platform that incurs significant control and static moderation in its operation; in addition to the added nodal processing and storage duties.

In terms of hindrances to operation, having a node that could be probed by any device with a path joining them, is a major load on the node's power consumption. Naturally, SNs are designed to cater for their current tasks, and go to sleep (duty cycle) when their operation is not required. This duty cycling scheme is a major player in power conservation and longevity studies in WSNs. Thus, allowing the node to be probed whenever needed contradicts with this critical metric of energy efficiency.

Moreover, adopting the view of SNs as service providers, especially when manifested in a M2M environment, would potentially create significant contention on nodal operation. That is, it would cause SNs to have to arbitrate requests for operation, and handle all the incurred communication overhead. The latter alone, is a significant source of power dissipation in WSNs.

There is a strongly proportional relation between communication frequency (in terms of how often a node has to communicate) and energy loss at nodes. This is incurred at the transceiver level and its circuitry and at the MAC layer as nodes contend for the medium to transmit the actual message, and the resulting coordination to remain on active transmission/reception channels to see through the completion of the transmission. A native approach for SN design is reducing communication and its overhead whenever possible. Simply performing idle-listening to wait for a service request consumes SN battery, as in many transceivers it equates with the power of receiving a message.

### B. *Crowd sensing*

A new paradigm of sensing has emerged in a domain called crowd or public sensing. It builds upon research in mobile computing and WSNs. The main idea is depending on users with smartphones, or specially supplied devices, to carry out sensing tasks and reporting back to a database. Prominent solutions following this paradigm, such as Cosm™ (previously known as Pachube), have been launched. Most of public sensing research takes place under the participatory sensing paradigm, in a classification depicted in Figure 1.

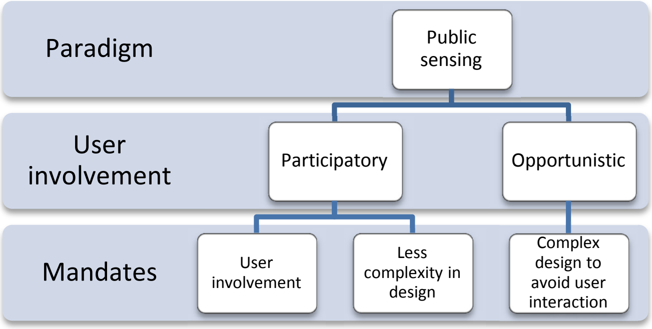

Fig. 1. Paradigms in public sensing

There are two main categories of user involvement, setting a distinction between public sensing paradigms. The first category is named opportunistic sensing, whereby users are not expected to take part in the sensing process. That is, whatever sensing devices they carry must be able to perform the data collection and reporting without user involvement. Although this offers a more attractive system for the users, it incurs significant complexity in design.

The second category is Participatory Sensor Networks (PSNs). The notion of enticing the crowds to actively carry out sensing tasks has been approached in many ways. Incentive schemes that promote either "reputation" or rewards based on monetary or credit systems, have been seen in many proposals. Although there is much merit in the claim of crowd-intelligence, and the dependency on ubiquitously available devices, there are many challenges that hinder the wide scale adoption of PSNs.

Xie et al have investigated bargain-based mechanisms to remedy the intrinsic tendency of nodes not to take part in participatory sensing systems [5]. This is a growing concern as PSN systems take a toll on smartphones when the users activate their applications, and little consensus has been seen in establishing fairness metrics in reporting and respective rewards [6]. In fact, in the case of large scale deployments (province, country, continent, etc) it is often impossible to ensure pre-determined trajectories and expected paths for mobile nodes taking part in the PSN, and their localization schemes remain a security issue.

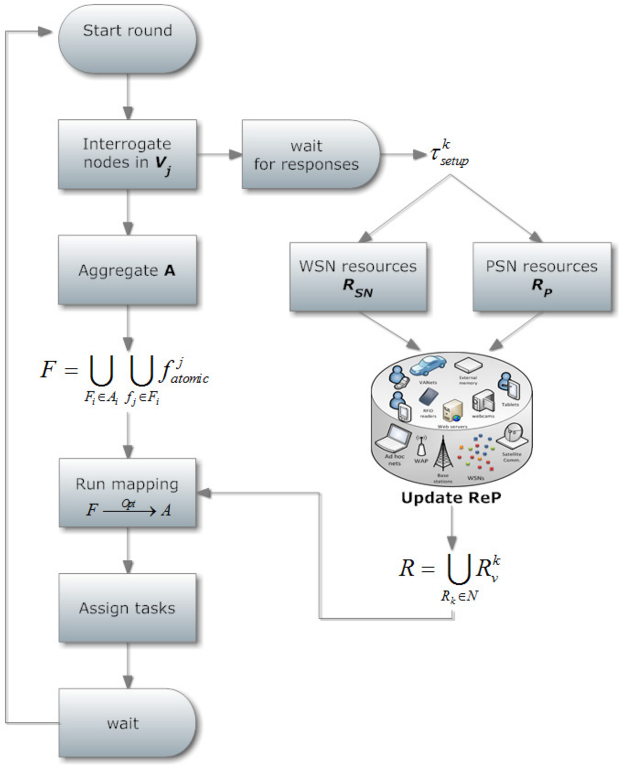

Fig. 2. Operation of DRR-WSN over WSN and PSN resources

## III. DRR-WSN SYSTEM MODEL

The view of applications as a set of functional requirements, with specific attributes coupled with that of the resources on which it would run, is also adopted. A significant notion presented here is the cost for using a resource. Since we now expand to include resources that do not necessarily belong to one proprietary, the utilization of resources across different networks is intrinsically a question of cost vs. utility. That is, how much would network owner A charge network B to use a given set of A's resources.

However, we argue that cross-network resource use is in fact a profitable architecture, for both parties involved. That is, a resource that is owned by A could generate revenue while it is idle (after serving its original functionality and awaiting its next round). On the other hand, network B could pay for the use of that resource when needed, instead of having to deploy nodes with such resources for occasional use. That both increases deployment cost and post-deployment impact of functional change, deeming many deployments expendable.

A core notion in this model is the resource encompassed by WSNs and PSNs. We formally define a resource as

Definition 1: *A resource is as an active entity in the network that has a pre-known functional capability, and the means to communicate its capability. Each resource has the capacity to cater for* $\mathbf{r_k}$ *requests, where* $\mathbf{r_k} \geq 1$. *Thus, it has* $\mathbf{r_k}$ *instances*

The core competency of a WSN in this paradigm is handling the sheer number of resources, both static and transient, that constitute its resource pool. Thus we first dissect the group of resources that would contribute to the resource pool.

The network is an aggregation of resources polled form WSN nodes $\boldsymbol{n^S}$ and PSN nodes $\boldsymbol{n^P}$. The ReP is an aggregation of these resources. However, $\boldsymbol{n^T}$ have deterministic sojourn times that are coupled with spatial limitations. Hence, we introduce the notion of dissecting the WSN deployment space into regions, and assume the presence of an entity dubbed the Arbitrator, in each one of those regions. Thus, the locality and relationship with $\boldsymbol{n^P}$ would be dictated by their relative position to an Arbitrator. Fig 3 highlights the relations and entities in DRR-WSN.

### A. *Task of the Arbitrator*

It is important to note that an Arbitrator need not be a specific device. It basically has the ability to communicate with neighboring nodes, has a pre-determined and static location, and retains, at the beginning of each round, information about neighboring nodes and their resources; that is the ReP. Thus, an arbitrator could also be formulated as a set of functional requirements that could be fulfilled by a more capable node at the beginning of the round, e.g., a laptop or smart vehicle.

Fig. 2 depicts the general operation DRR-WSN and the phases in which it operates in each round. At the beginning of the round, the arbitrator interrogates current nodes in its vicinity, and collects the resource profiles of each while the arbitrator is still in its network setup phase. The local arbitrator then aggregates these resources, along with the functional requests of the applications to run on the network (by probing applications).

The ReP on each local arbitrator is then updated with these resources, and DRR-WSN finds an optimal assignment of functional requests to resources. This assignment mandates network operation until the whole process is re-iterated. That is, till the round is completed.

More importantly, when a resource is used by a given application, token exchange is regulated via the arbitrator, to repay the resource owner. This is an important component of this model since resources are mostly owned by different users, and a given application could run on resources from multiple owners. To support consistency, resources will be rewarded by tokens even if the application and resource used belong to the same entity. The matching algorithm takes into account the least total cost for matching all functions to resources, regardless of providing owner.

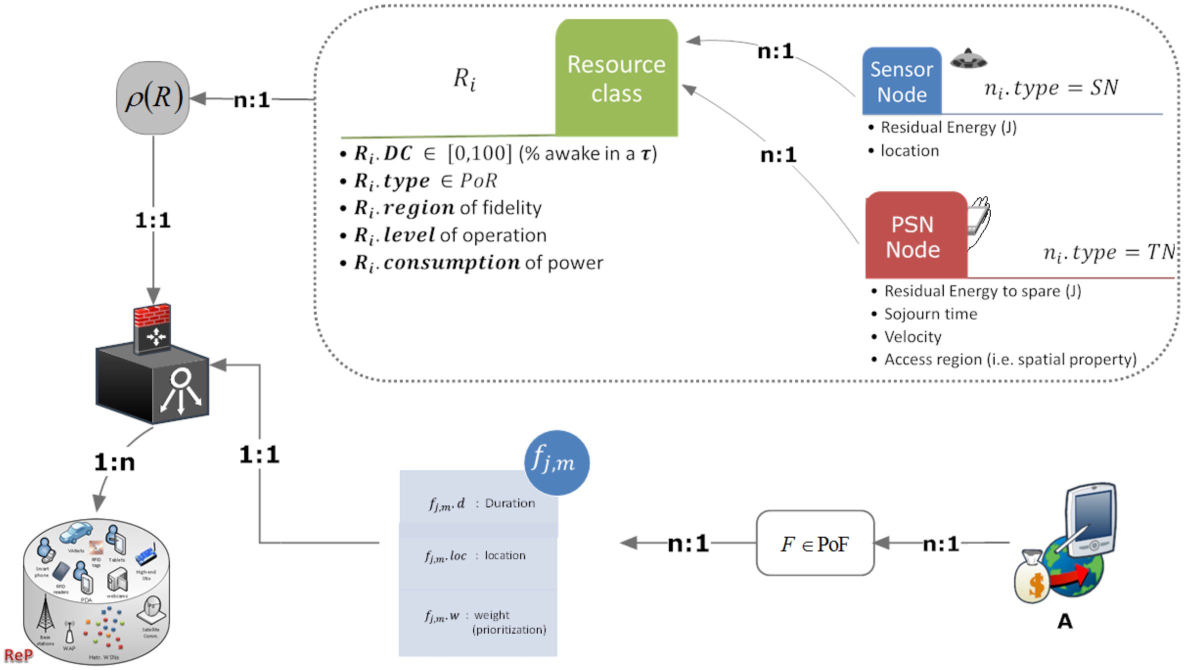

Fig. 3. A relational overview of resources over WSNs and PSNs in contract to functional requirements of applications

**Algorithm 1: Arbitrator operation**

```
Input:
$b_\alpha$ : Arbitrator $\alpha$
T : Maximum number of rounds for $a_\alpha$
RePα: Current resource pool at $a_\alpha$
Output:
  none
1.  Begin
2.  $\tau_k \leftarrow \Delta_{init}$        // initial round duration
3.  for $k \leftarrow 0$ to T do
4.    while ($\tau_k^{setup}$)  //terminate with timer
5.      in parallel   //run concurrently
6.        do $F_\alpha \leftarrow$ Probe_apps(Loc($b_\alpha$))
7.        do $R_\alpha \leftarrow$ Populate_ReP(Loc($b_\alpha$))
8.    Update_global_ReP($R$)
9.    $\Psi \leftarrow$ Match($b_\alpha$, $F_\alpha$ , $R_\alpha$)
10.   $\tau_k^{operational} \leftarrow$ Compute_Tau(RePα)
11.   while ($\tau_k^{operational}$)
12.     Run($\Psi$)
13. End
```

The operation of DRR-WSN is detailed in Algorithm 1. This operation is carried out at each arbitrator in its own vicinity. At the beginning, the arbitrator starts with an empty resource pool, and an arbitrary duration for a round. It interrogates both local resources (static and transient) to populate the local ReP, denoted as $\text{ReP}_\alpha$, this corresponds to function call **Populate_ReP**. Then local applications are probed for their functional requirements; **Probe_apps**. Viable resources are then registered and updated at the repository of the head Arbitrator (if any). A matching matrix is then constructed at $\text{ReP}_\alpha$ based on dynamic assignment heuristics that dictate the optimal matching $\Psi$, computed by **Match.**

A new round duration is computed in line 10 based on the variability in dynamic resources in the current ReP and introduced as the new round duration for the next cycle. The new assignments are executed by the selected resources for the remainder of the current round.

## IV. PERFORMANCE EVALUATION

The performance evaluation for DRR-WSN adapting to PSN resources is carried out in MATLAB. We set up an experiment with variable number of nodes, both static and transient, and adopt a dynamic assignment scheme of functional requirements for each run. The locations of nodes follow a uniform random distribution over the deployment region. We ran our simulation models with different energy levels for sensing nodes, to fall randomly in the range of 80% to 100% of an initial battery power set to a maximum of 3 kJ. PSN nodes also start with a random battery level in the same range, with an upper limit of 5 kJ (as dedicated for DRR-WSN). We assume that PSN nodes hold a vastly heterogeneous pool of resources, and sensing nodes have a more homogeneous pool. In our experiments we assume static sensing nodes have an arbitrary number of resources from the set of {'Temperature sensor' ; ‘Light sensor’ ; 'Micro controller' ; 'Memory' ; 'Transceiver' ; 'Camera' ; 'Radar' }. Transient resources could have any of these resources, in addition to a more smartphone oriented pool of resources that we abstract as {‘GPS’; ‘microphone’; ‘geomagnetic’; ‘barometer’}. Naturally, each node holds a transceiver, micro controller and one type of sensor as a minimum.

In Fig. 4. we depict a sample run of DRR-WSN. With a deployment region of 300 x 300 m, 50 functional requests are distributed over a network of 100 nodes, 30 of which are PSN nodes.

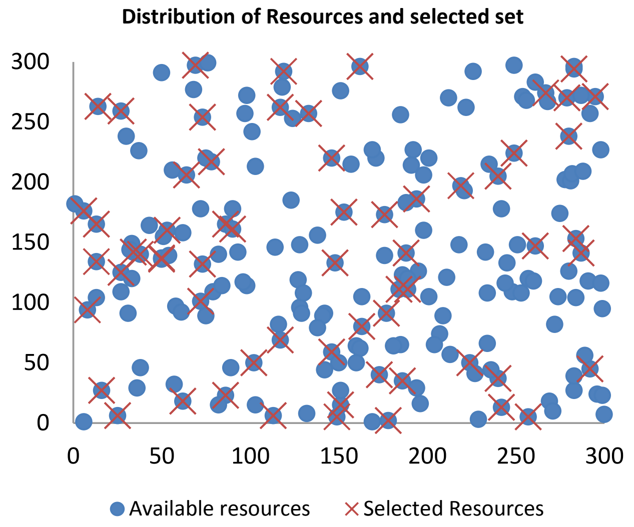

Fig. 4. Distribution of resources in a typical scenario (run), and the resources selected for the current functional requests

The major motivation for synergy in DRR-WSN with PSN resources is maximizing functional gain while reducing the cost of carrying them out. Simply put, with many resources existing in the ReP, it is important for the Arbitrator to select the least costing resources to satisfy the functional demands.

To capture the effect of cost reduction on each network, we assume an abundance of resources that would allow for a network to run its own functional requests on its local resources. However, PSN nodes enter the vicinity and offer their resources for monetary gain. As the energy reservoirs get depleted at the network, it would serve both network longevity and cost reduction to utilize non-local resources. This is presented in contrasted scenarios, whereby each application is assessed in terms of its cost impact as it runs for multiple rounds on its own resources, or when it utilizes DRR-WSN to depend on other abundant resources.

We note however that the same resource exhibits different energy impacts, depending on the underlying hardware. That is, a smartphone might consume more energy to run its camera in contrast to a lower end camera on some WSNs.

The impact of transient resources on network performance is complex. On one hand, they leverage functional requests and aid energy-deprived sensor nodes. On the other hand, they incur significant costs to the owner of the static nodes as they charge for carrying out the tasks.

We next examine the operation of DRR-WSN aided with PSN resources, over a number of dynamic rounds. Fig. 5 depicts DRR-WSN operation with 60 static nodes, for 50 rounds, on a typical region for an arbitrator of size 100 x 100 m. Each round has a round duration of 5000 sec in addition to a variable round time in the range of [0,5000] dependent on the impact of PSN resources. PSN resources have a random effective time in the range [500,1500], and arrive according to a Poisson process with average 1000 seconds.

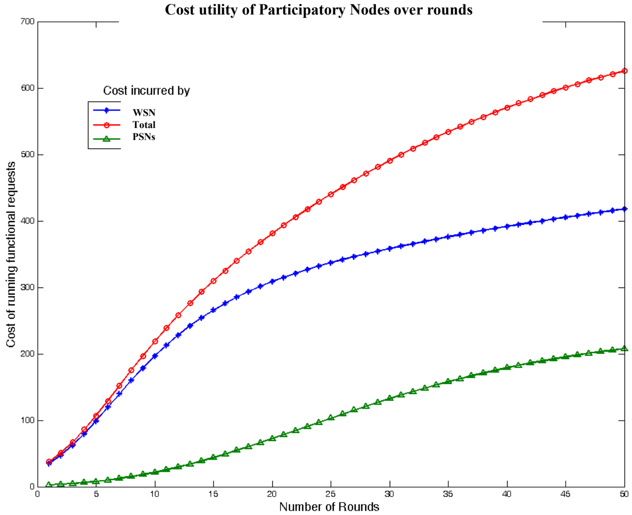

Fig. 5. PSN nodes leveraging WSN performance over rounds

The network significantly depends on WSN resources with lower cost incurred for functional tasks at the earlier rounds. However, due to the relative pricing of resources dictated by PSN cost models over later rounds, it becomes more cost effective to depend on transient resources. An interesting phenomena occurs after approximately 20 rounds, when energy reservoirs at both WSN and PSN nodes start witnessing equal depletion, hence the uptake of resources from both classes of resources grow in a balanced pattern.

It is important to note the impact of another factor, which is the growth scaling factor associated with PSN nodes. In Fig. 5 both WSN and PSN nodes shared an equal cost growth since it has the steadiest increase in resource valuation. However, PSN resources, such as in smartphones, often have less latency to carry out functional requests as their batteries suffer higher depletion. To capture this factor, we demonstrate in Fig. 6 an experiment set with PSN resources growing twice as fast in valuation in proportion to energy depletion than their WSN counterparts. As a control factor, the experiment is run under the same arrival rate and effective time as in the experiment depicted in Fig. 6. The resulting network cost is evidently reduced by an average of 6% when transient resources have higher valuations at later rounds.

The downfall, however, is the larger impact on residual energy at WSN nodes. Thus, determining the optimal balance of lifetime versus running costs largely depends on the resource valuations set by WSN and PSN nodes.

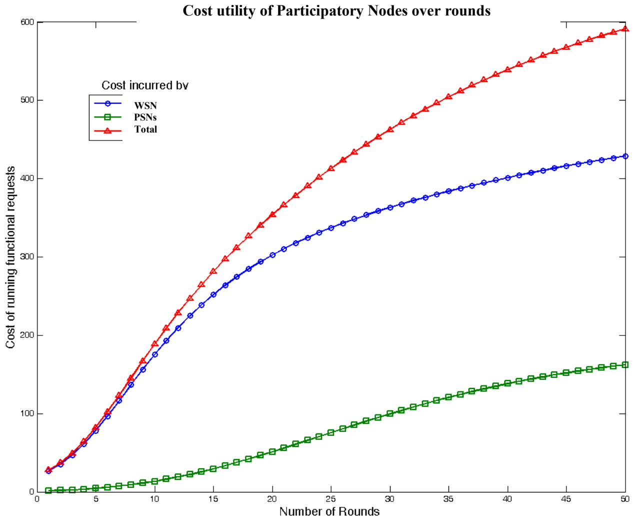

Fig. 6. Impact of increasing elastic pricing of PSN resources on DRR-WSN operation

## V. CONCLUSIONS

Current practices for designing and deploying Wireless Sensor Networks persistently yield application specific networks. Such limitation in applicability has thus far been driven by a basic tradeoff between functionality and resource availability - a tradeoff that has received great research attention over the years. DRR-WSN parts from this traditional model and offers a new WSN approach that decouples application considerations from network architecture and protocol. More importantly, we proposed a model whereby Public Sensing systems could reap the benefit of resilient WSN operation to expand their reach and reliability. In return, WSNs will capitalize on resource abundance in PSNs which require no deployment *apriori*. RR-WSN promises a great potential for realizing a truly large-scale WSN unity that alleviates resource waste in redundancy, and delivers maximized utility for required applications.

## ACKNOWLEDGMENT

This research is funded by a grant from the Ontario Ministry of Economic Development and Innovation under the Ontario Research Fund-Research Excellence (ORF-RE) program.

## REFERENCES

[1] S. Kanhere, "Participatory sensing: Crowdsourcing data from mobile smartphones in urban spaces." In *Distributed Computing and Internet Technology*, Springer Berlin Heidelberg, pp. 19-26, 2013.

[2] A. Taha, " Towards comprehensive RRM frameworks for heterogeneous wireless networks", In *Proceedings of the ACM conference on Information Science*, Technology and Applications, pp. 1-7, 2009.

[3] H. Yim and K. Lee, "A DLNA-Based Efficient Mechanism for Interconnecting Mobile Devices in Ubiquitous Environments." In *Proceedings of the IEEE/ACM International Symposium on Distributed Simulation and Real Time Applications*, pp. 143-144, 2012.

[4] S. Oteafy and H. S. Hassanein, "Re-usable Resources in Wireless Sensor Networks", IEEE Global Telecommunications Conference, pp. 1-5, 2011.

[5] X. Xie, H. Chen, and H. Wu, "Bargain-based stimulation mechanism for selfish mobile nodes in participatory sensing network." In 6th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON), pp. 1-9., 2009.

[6] K. Herrmann and D. Fischer. "Resource Management in Public Sensing-Challenges and Requirements." Electronic Communications of the EASST, 2011.

[7] L. Mottolaand G. Picco, "Programming wireless sensor networks: Fundamental concepts and state of the art." ACM Computing Surveys (CSUR), Vol. 43, no. 3, 2011.

[8] G. Wu, S. Talwar, K. Johnsson, N. Himayat, and K. Johnson, "M2M: From mobile to embedded internet." IEEE Communications Magazine, Vol. 49, no. 4, pp. 36-43, 2011.