Ubiquitous Robust Data Delivery for Integrated RSNs in IoT

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Abstract— **In this paper, we present URIA, a Ubiquitous Robust Integrated Approach for data delivery in integrated RFID-Sensor Networks (RSNs). The proposed approach deploys ubiquitous wireless nodes equipped with transceivers as couriers between integrated reader/relay nodes and access points in an IoT setting. In addition to guaranteeing a specific level of connectivity across the network, URIA maintains constraints on delay, such that a multi-path minimal-delay route is always provided between any source-destination pair. Our approach is formulated via a Semi-Definite Programming (SDP) solution and is compared against other IoT integrated schemes targeting connectivity and delay metrics. Simulation results show that our proposed approach outperforms rival schemes in terms of total latency and delivery rate. This is achieved while considering vast data generation rates, instantaneous topology changes, and high probabilities of failure over the established end-to-end paths.**

I. INTRODUCTION

The Internet of Things (IoT) promises to provide objects with identities and the abilities to communicate among themselves and with the environment on an ultra-wide scale. The very first *things* to be considered for IoT were simple Radio Frequency IDentification (RFID) tags and readers [1]. However, IoT applications have advanced beyond the mere identification of objects to incorporate levels of interaction and data delivery exceeding those of RFID technology.

In order to overcome the limitations of RFID and realize the IoT concept into the real world, efficacious IoT approaches must seamlessly integrate other wireless technologies with RFID. Wireless Sensor Networks (WSNs) are considered among the most prominent options, forming what is known as RFID-Sensor Networks (RSNs) [2]. RSNs represent heterogeneous platforms enabling an abundance of new applications into the IoT context while providing identification, tracking and sensing capabilities.

One of the most challenging performance metrics in RSNs is connectivity. On one hand, the heterogeneous nature of integrated architectures is responsible for interoperability complications. Lack of interoperability creates disconnected islands of nodes across the network. Connectivity in IoT is further challenged by nodal mobility [3] and, consequently, temporal partitioning especially at bottlenecks where the edges between vertices are minimal.

We define an *Internet of Things Setting* by the following four main characteristics: a) Ability to identify b) Seamless integration c) Ubiquitous & robust connectivity and d) Delay-tolerance. We elaborate on each of these characteristics as follows.

IoT assumes that *things*, being physical or virtual objects, have digital functionalities and can be identified and tracked automatically by their corresponding neighbors in order to implement any data delivery schemes. Connectivity between various parts of the IoT network is a consequence of seamless integration between its heterogeneous components. In this regard, we use the term *ubiquitous* to refer to the network's ability to assume connectivity anywhere and anytime. Here, connectivity is not only viewed as an infrastructure but rather as a *task* that nodes need to take responsibility of as a reaction to the ever-changing topology. Being *robust*, on the other hand, means that more than one path per each pair of nodes must be guaranteed at each data exchange cycle to avoid partitioning.

Moreover, delay-tolerance is a self-embedded attribute in IoT settings. In reality, a given node in an IoT setting has only partial knowledge, if any, regarding the full path assigned to packets under its possession. In such situations, nodes are required to store and carry the packets until a suitable forwarding opportunity arises, in a store-carry-forward (SCF) fashion [4]. We state that any IoT data delivery scheme must be delay-tolerant to cope with this intermittent connectivity. Yet, some data might be more critical and the delivery scheme must react accordingly by providing links with minimum delays.

The aforementioned intermittent connectivity characteristic has a vital impact on data delivery in IoT settings. To this end, we list our contributions in this paper as follows:

- We classify nodes within an RSN layout into three classes: simple (RFID tag or sensor) nodes (SNs), integrated (RFID reader/rely) nodes (INs) and courier nodes (CNs).
- We consider a courier-based data delivery approach for RSNs called URIA (Ubiquitous Robust Integrated Approach). Our approach utilizes the mobility of CNs to guarantee a specific level of connectivity between INs and access points (APs) in the network. URIA also addresses any constraints on delay when selecting CNs.
- Finally, we provide a solution based on a Semi-Definite Program (SDP) based on Laplacian matrix and λ_2 values to tackle the guaranteed connectivity objective, in addition to catering to delay constraints for applications that are less delay-tolerant.

The reminder of this paper is organized as follows. Section II surveys related work on integrated schemes that are either

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delay-based or connectivity-based. Section III presents our system models. Section IV describes our connectivity methodology and the SDP formulation. Section V evaluates the performance results of our approach in comparison to other integration schemes. Finally, Section VI concludes this paper.

II. RELATED WORK

Our approach has "connectivity" as its objective while addressing delay constraints. In the following, we review other integrated approaches in the litereture that are either delay-based or connectivity-based.

A. *Delay-based Approaches*

Data delivery in delay-tolerant sensor networks has been covered extensively [5]-[7]. Among the most popular are History-based (probabilistic) [5] routing. Also of particular interest social based forwarding schemes such as [6] and [7]. Other DTN delivery schemes are based on utilizing the mobility patterns of nodes in the topology. The selection of the most appropriate routing scheme is mainly application dependent.

We note, however, that routing in integrated RSNs has not been addressed in existing DTN schemes. Thus, we proposed DIRSN; a Delay-tolerant framework for Integrated RSNs [8]. DIRSN applies an architectural model similar to the one we introduce here while addressing only delay constraints. It takes into account that relays may lose the connection to their corresponding access points and considers the variations between IoT nodes in terms of mobility and connectivity capacities. Hence, DIRSN employs a decentralized ILP-based delay-tolerant solution to locate the optimum set of CNs per time-round. This solution aims toward guaranteeing minimum-delay-connectivity between INs and APs in the network through CNs. In a real-life scenario, CNs would be represented by cell-phones, chips on vehicles, advanced sensors, or any mobile node with sufficient transmission and buffering capabilities to exchange routing tables with neighboring nodes and discover routes to deliver data within a limited amount of time. Such couriers would roam across the platform following their own random or deterministic patterns; read data held by both SNs and INs via short-range wireless communication and finally transmit the collected data to some AP within the premises.

DIRSN is a cost-effective delay-tolerant routing approach. Hence, it was chosen as a representative of this category of approaches. However, DIRSN does not consider operating under harsh environments. Thus, it did not include connectivity as an objective.

B. *Connectivity-based Approaches*

In general, connectivity problems [9][12] can be dealt with either by populating relay nodes (RNs) or by utilizing mobile nodes. For example, in [10], the lowest number of relays is added to a disconnected static WSN, so that the network remains connected. In [11], mobile nodes are used to address k-connectivity requirements by identifying the least count of relays that should be repositioned in order to re-establish a particular level of connectivity. However, connecting nodes over IoT is more challenging because of the aforementioned heterogeneity issues and due to the high cost of deploying relay nodes. In addition, transmission in IoT cover distances that might exceed the communication ranges of most relays.

To address this complexity, [12] propose a two-phase Optimized Relay Placement (ORP) approach. The first phase sets up a connected network backbone by using a reasonably small number of relays, which was called First-Phase Relay Nodes (FPRNs). The first phase also finds a set of candidate locations for relays that are deployed in the second phase, which we call Second-Phase RNs (SPRNs). The second phase aims at deploying the available number of SPRNs in the candidate positions obtained from the first phase, in such a way that maximizes the WSN connectivity.

The approach we propose here, however, connectivity is achieved by utilizing active human-participation (i.e. personal devices and vehicles) via CNs rather than passive recipients or relays. This method has several advantages in terms of reducing the cost of large-scale network deployment since we are utilizing pre-existing resources. Also, couriers are mostly on the move, so their utility is manifested in different areas of need. Areas that usually require higher rate of services (identification and sensing) would already be the areas of higher population of users carrying courier resources.

III. SYSTEM MODELS

In this section we describe the network model, delay model and communication model used in our approach. All models are specifically targeting connectivity over RSNs in IoT.

A. *Network Model*

The IoT data delivery approach we introduce here is referred to as Ubiquitous Robust Integrated Approach (URIA). On one hand, URIA adopts a non-centralized scheme that avoids partitioning in the ever-changing topology of an IoT by maintaining a minimum level of connectivity for a given layout. In addition, URIA maintains constraints on delay by allowing CNs to self-compute minimum-delay routes for their data transfers.

Fig. 1 illustrates the basic blocks of the architecture upon which URIA is based. It incorporates:

- Integrated Nodes (INs) representing the integrated part of the architecture. They perform the combined roles of RFID readers and wireless relays to Access Points (APs), simultaneously.
- Simple Nodes (SNs) represented by passive RFID tags and simple sensor nodes, each performing their own protocol. LNs are assumed to be distributed densely over the topology and may be fixed or mobile depending on their corresponding applications. They are dedicated for data collection and are relieved by INs from relaying duties.
- Courier Nodes (CNs) represented by ubiquitous devices in the IoT that enjoy variant levels of storage and routing capabilities. A courier is presumably moving towards or residing within the communication range of an AP. These nodes are employed to establish and ensure connectivity, in addition to maintaining delay constraints, between INs and APs via SCF routing.

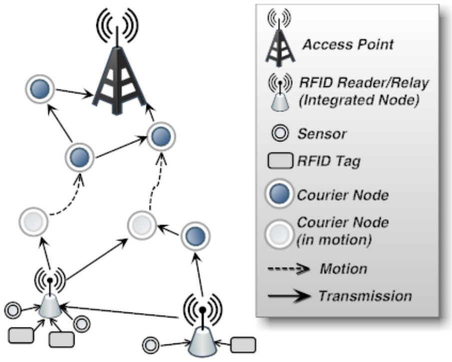

Fig. 1. Integrated architecture assumed by URIA.

B. Delay Model

The SDP solution presented by URIA minimizes the worst delay experienced between any IN/AP pair. It assumes a generic discretized delay metric that can be used in any IoT system.

Due to dense network topologies associated with IoT, a relatively long multi-hop path can easily exist between the source node and the corresponding AP. Thus, the delay components we have to consider are dominated by the transmission delay ψ, and the processing delay ω. These delays are extremely dependent on the processing capabilities of the relaying device. They vary based on the utilized technology and its corresponding standards. Accordingly, we define a discretized delay step D which is the delay a packet would experience in a single hop travel. Then, the discrete delay over a single-hop link (i, j) would be:

$$D = \lceil \omega + \psi \rceil \tag{1}$$

The discrete delay over a multi-hop path i is the sum of the discrete delays of single-hop links that constitute that path, and is computed by:

$$D(i)_{total} = \sum_{total\ hops} \lceil \omega + \psi \rceil \tag{2}$$

Consequently, the bottleneck delay in the established communication network between the AP and its corresponding INs will be the maximum $D(i)_{total}$ amongst the paths connecting an AP with the INs. Note that the propagation delay is neglected in this research due to the assumed wireless communication means in the targeted IoT application.

C. Communication Model

We assume a probabilistic model in which the probability of communication between two wireless devices decays exponentially with distance and takes into consideration surrounding obstacles and hindrances. This model can describe the path loss[1] in the targeted site by taking into consideration the effects of the surrounding terrain on the power (P_r) of received signals as follows [13]

$$P_r = K_0 - 10\gamma \log(d) - \mu d \tag{3}$$

which follows a log-normal distribution centered around the average power value at the device location. Here K_0 is a constant incurred at transmission (of transceiver electronics), which is derived from the mean heights of the transmitter and receiver. Having d as the Euclidean distance between the transmitter and receiver, and γ as the path loss exponent, we adopt μ as a normally distributed random variable with zero mean and variance, i.e. $\mu \sim \mathcal{N}(0, \sigma^2)\mu \sim \mathrm{N}(0, \sigma^2)$. Since the received signal could be quantified using P_r, we devise a lower threshold on the signal level to deem communication successful. Denoting it as $P_{\min}$ over distance d (between transmitter and receiver), we denote the probability of successful communication as:

$$P_c = P\left(P_r(d) \geq P_{\min}\right) \tag{4}$$

IV. URIA APPROACH

URIA considers both connectivity and delay constraints in a given IoT setting. In the following, we provide a description of an application scenario, in addition to the formulation of our solution.

A. Application Example: E-health

Applications that require guaranteed connectivity with constraints on delay or delivery time are common in the context of IoT. In particular, we target e-health (also known as emergency response systems) applications [14], which have a high demand for connectivity and high sensitivity to failure. We base our scenario on observing that mobility patterns of most CNs are not arbitrary but rather follow recurrent traces produced by human mobility or that of vehicles in a city section. Thus, courier-based data delivery can take advantage of the probabilistic and social attributes of such mobility traces.

The use of integrated RSNs in e-health applications allows real time monitoring of people with health problems, leading to earlier diagnosis. Vital parameters such as heart rate, breathing rate and blood pressure can be measured by lightweight SNs worn by the individuals to record data on multiple health parameters. Automatic alerts can be immediately sent to medical staff to warn of deterioration in patients' condition. The delay constraint of the call depends on the urgency of the situation.

In the default case and since SNs are limited in their transmission capabilities; communication is initiated by neighboring INs or CNs on periodical bases if transmission distance permits. The readings acquired form SNs are delivered to the access-point (i.e. hospital or physician's clinic) without any delay constraint. However, once the readings indicate a critical condition, they are treated by the system as urgent and routs with minimum delay are computed to deliver them.

If a relay on an IN receives the signal, it may communicate immediately with a transceiver mounted on any CN in the vicinity . If the taxi's routing table indicates that it is soon to pass near a hospital sometime in the future. In another scenario, the taxi, while in transit, may identify an ambulance and forward the alert to it. The ambulance's paramedics would head immediately to the source of the alert after informing the hospital to prepare its staff for the case. However, to guarantee some level of connectivity, URIA insures that other copies of the original alarm are also sent to the neighboring CNs/INs that

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[1] Path loss is the difference between transmitted and received signal power.

will utilize their mobility or social resources and evaluate them against their failure or connectivity metrics to decide on forwarding the message.

B. Problem definition & formulation

According to the aforementioned IoT settings and architecture, we define our deployment problem as follows:

Given a pool of candidate mobile/static N couriers in an IoT architecture, select the best subset of N to deliver data from C_c INs to a single AP while satisfying connectivity and delay constraints.

To solve this problem, we develop an SDP-based solution that determines the optimum subset of CNs in a manner that insures specific connectivity level with minimal delay across the network. We represent our layout by an initially connected graph, denoted by B, whose vertices are the INs and CNs in the setting. The algebraic connectivity of B is measured by the second smallest eigenvalue λ_2 of the Laplacian matrix $L(B)$. Our solution aims toward satisfying a specific algebraic connectivity while minimizing the data delivery delay. We apply this method to other RSN deployment approaches and compare the resulting delivery rates to prove its superiority.

We assume discretized rounds from which our scheme selects routing paths. Selection is based on locating the most suitable couriers passing through these paths. This is determined according to minimum delay and connectivity-level constraints calculated from the INs up to the AP.

The location of the best M couriers in the proximity of each IN and available CN in the network is achieved by periodically exchanging routing tables and/or registration records between neighboring nodes. This location process is repeated at the beginning of each round. The mobility history of the neighbors is examined against the communication range of the corresponding destination node(s). Based on the results, forwarding candidates are defined according to minimum delays. The solution we use to conduct this approach is based on an SDP formulation which, in turn, requires defining the following constants and variables:

Constants:

C_c: Total candidate couriers.

D_{max}: Maximum delay to transfer a data unit from an IN to the AP.

IG_i: Data generation rate of a IN i (based on the underlying connected SNs per IN).

t_i: Traffic capacity of a IN i (i.e., maximum bandwidth available for node i per round).

T_i: Traffic capacity of a courier node i.

N: Maximum couriers' count that can be used per round.

$N(i)$: is a set of neighboring candidates such that $j \in N(i)$ if node j is within the transmission range of node i (i.e. $P_c(i,j) \geq \tau$).

$M(i)$: is a set of indices such that $j \in M(i)$ if node j is within the transmission range of a courier i that can reach an AP.

Q: A quality factor that is predefined based on the network specifications and user requirements.

n: Total connected INs, and APs.

I_{nxn}: Identity matrix of size n by n.

Variables:

α_i: A binary variable equals to 1 when a courier at position i (associated with an (x,y) coordinate) is chosen by an IN to relay its data to the AP, and 0 otherwise.

f_{ij}: is the flow from a super node i to courier j (i.e. the data units to be sent from i to j).

l_{ij}: is the flow from a courier node i to courier j.

$L(\alpha)$: is the Laplacian matrix of the connected graph formed by n INs/Aps.

S: is a scalar variable representing the 2nd smallest eigenvalue in $L(\alpha)$.

Our policy of minimizing the delivery delay implies minimizing the total path length towards the AP without overwhelming the integrated network. This is achieved by locating a courier set that maintains the shortest path from each IN to an AP while considering their varying node/link capacities and load balance. We aim for each IN to deliver data to its corresponding AP with the least delay. In addition, this set of couriers must guarantee a specific level of connectivity ($\geq Q$) in the network formed by INs and APs. The SDP formulation in Fig. 2 represents our solution to address these constraints. Eq. (5) is the objective function which minimizes D_{max}. Eqs. (6) and (7) satisfy the traffic capacity constraints available to INs and CNs, respectively. Eq. (8) guarantees that if no courier is selected (i.e., $\alpha j < 0.5$), no flow is sent to courier at position j. Eq. (9) makes D_{max} the maximum delay over all INs seeking the AP (note that we minimize D_{max}). Eq. (10) satisfies the constraint that only N couriers are available. Eq. (11) formulates the mathematical representation of the minimum required nodes/links for a network to partition. Eq. (12) represents the connectivity-level constraint of the formulated network.

In this approach, we assume a connected graph constructed by the INs and APs. Connectivity of this graph is measured by considering its Laplacian matrix $L(\alpha)$ [12]. The Laplacian matrix is a two dimensional matrix that has -1 at the element (i,j), if there is a connection between nodes i and j. It has an integer positive number at the element (i,i) that represent the number of edges connected with node i. Given $L(\alpha)$, the graph connectivity (or algebraic connectivity) is mathematically measured by computing the second smallest eigenvalue $\lambda 2$ of the Laplacian matrix $L(\alpha)$, where $\lambda 2$ indicates the minimum number of nodes/links whose removal would disconnect the graph of SNs and APs.

By maintaining a $\lambda 2$ value that is greater more than a value Q, we assure a specific connectivity level in the formulated network (graph). This is due to the proportional relation between the value of $\lambda 2$ and the number of nodes/links which can cause network partitions [12]. In order to maintain the $\lambda 2$ value, we assume Cc candidates among the available CNs. We want to choose the optimum N CNs amongst these C_c candidates with respect to connectivity; where N is constrained by a cost budget and/or available resources. We can then formulate this robustness objective using the two constraints in Eqs. (11) and (12). Then, we formulate and solve an optimized SDP with an objective function of minimizing the delay while assuring a specific connectivity-level ($=Q$) without exceeding the available count of couriers from which we achieve our ubiquitous connectivity.

$$Minimize \quad D_{max} \tag{5}$$

$$Subject\ to$$

$$\sum_{j\in N(i)} f_{ij} \le t_i, \qquad 1 \le i \le IN_{total} \tag{6}$$

$$\sum_{j\in N(i)} f_{ij} + \sum_{j\in M(i)} l_{ij} \le T_i, \quad 1 \le i \le C_c \tag{7}$$

$$\sum_{i\in M(j)} l_{ij} \le \alpha_j \sum_{1\le i\le SN_{total}} IG_i\,, \ 1 \le j \le C_c \tag{8}$$

$$\sum_{j\in N(i)} D_{single}.f_{ij} + \sum_{j\in M(k)} D_{single}.l_{kj} \le D_{max},$$
$$1 \le i \le IN_{total}, 1 \le k \le C_c \tag{9}$$

$$\sum_{i=1}^{C_c} \alpha_i = N,\ 0\ \le \alpha_i \le 1 \tag{10}$$

$$S\left(I_{nxn} - \frac{1}{n}11^T\right) \preccurlyeq L(\alpha) \tag{11}$$

$$S \ge Q \tag{12}$$

Fig. 2. SDP formulation for URIA

We remark that the SDP in Fig. 2 can be modified to handle more complex capacity constraints (e.g., given different weights to different links incident to a single IN and/or CN). We show a general case here to simplify the presentation.

V. DISCUSSIONS & RESULTS

In this section, we discuss our simulation approach, simulation model and its numerical results.

A. *Simulation Environment*

Using MATLAB, we simulate randomly generated RSNs which have the graph topology proposed in the previous section and subject to varying probabilities of failure (PoF). To solve the previously modeled SDP optimization problem, we used the SDPA-M MATLAB Package [15].

B. *Performance Metrics & Parameters*

To evaluate our URIA approach, we tracked the following performance metrics:

1) Connectivity (λ_2): This criterion reflects the established network robustness under varying PoF. It gives an indication for the designed RSN efficiency in IoT settings.

2) Average delay: Defined as the time required to deliver a data unit to an AP.

3) Average packet loss percentage: The percentage of transmitted data packets that fail to reach the AP.

Three main parameters are used in the performance evaluation: *1)* Probability of Failure (PoF), *2)* Number of available couriers (*N*), and *3)* the Average Generation Rate (AGR). PoF is the probability of connectivity failure in the network, due to node movement, node damage, link failure, etc. We chose this parameter as it is a key factor in reflecting the IoT settings in terms of heterogeneity and dynamics. As for the *N*, it represents the availability of resources in providing improved alternatives. The AGR reflects the scalability and applicability of the proposed approach in large-scale and excessive data exchange applications.

C. *Baseline Approaches*

The performance of URIA is compared against two approaches targeting connectivity and delay objectives, respectively. The first is ORP [12] an algorithm based on an SDP that maximizes the formulated network connectivity by maximizing λ_2. ORP opts to establishing a robust network by selecting the most appropriate couriers The second rival approach was represented in [8] as DIRSN; an integrated architecture pursuing an ILP which selects the best subset of couriers to maintain the least delay. Both ORP and DIRSN approaches are used as a baseline in this research due to their efficiency in linking INs with APs in integrated architectures while considering connectivity and delay constraints.

D. *Simulation Model*

The three deployment schemes: ORP, DIRSN, and URIA, are executed on randomly generated RSN graph topologies in order to get statistically stable results. The graphs' dimensions are 500×500*m* and contain 500 nodes, 300 of which are CNs, all following the Random Waypoint mobility model [16]. The average results hold confidence intervals of no more than 2% of the average values at a 95% confidence level. For each topology, we apply a random PoF values, and performance metrics are computed accordingly. A Linear Congruential random number generator is used for random RSN. We assume a predefined fixed time schedule for traffic generation at the deployed INs. Intermediate couriers are selected by applying the three approaches.

E. *Simulation Results*

We ran simulations to compare the three aforementioned approaches in terms of delay vs. connectivity, PoF vs. packet loss and data generation rate vs. packet loss

URIA is intended to achieve the best of both ORP, which targets connectivity as an objective, and DIRSN, which specifies minimum delay as its objective function. It is apparent from Fig. 3 that URIA accomplishes astounding results in terms of both metrics. It is worth mentioning that under lower lambda2, URIA's performance in terms of delay is worst that of DIRS and ORP. However, as the connectivity constraint increases, both ORP and DIRSN lose the lead and maintain an almost steady delay, with DIRSN attaining a better score than ORP (48 *msec* vs. 68 *msec*). URIA, on the other hand, outperforms both approaches with a minimal delay that drops exponentially as connectivity increases. Fig. 3 shows that delay virtually fades as *Q* approaches 0.3.

In Fig. 4, we notice that DIRSN provides the best performance in terms of delivery under continuous topology changes and consequence delay, represented in PoF. However, since DIRSN targets delay as its objective function, its feasible search space is limited by the connectivity constraint that increases as PoF rise. As the PoF exceeds the 20% limit, DIRSN's performance deteriorates in favor of URIA that reacts to both delay and connectivity, and eventually surpasses DIRSN. The same could be said about ORP that slightly outperforms URIA until the 10% PoF level. Beyond that point, the effect of URIA's delay-tolerant formulation gives it an advantage over ORP's connectivity-based algorithm.

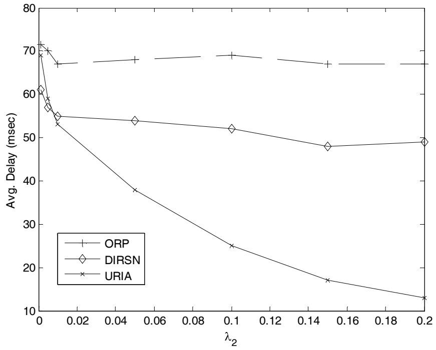

Fig. 3. Delay vs. Connectivity

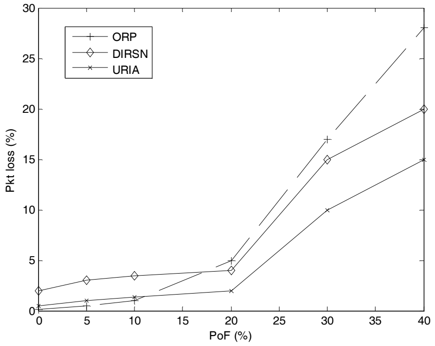

Fig. 4. Packet loss vs. Probability of Failure

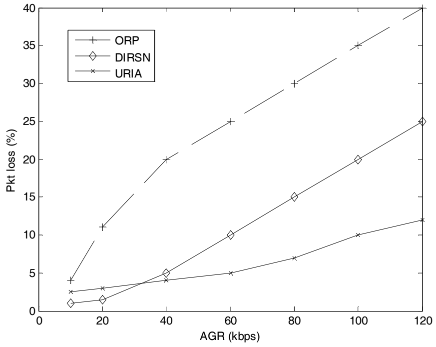

Fig. 5. Packet loss vs. Avg. data generation rate

In Fig. 5, URIA outperforms both ORP and DIRSN in terms of packet loss as packet generation rate increases. This reflects URIA's scalability and applicability in large-scale and excessive data exchange applications. Again, we observe that ORP is a connectivity-based approach and it handles delivery poorly as AGR increases until it reaches a level where it drops 40% of its packets. DIRSN, being a delay-tolerant approach that incorporates a courier-based delivery algorithm, performs better than ORP under higher rates of data exchange.

VI. CONCLUSION

In this paper, we present URIA, a Ubiquitous Robust Integrated Approach for data delivery in integrated RFID-Sensor Networks (RSNs). URIA considers both connectivity and delay constraints in a given IoT setting. From an architectural point of view, URIA utilizes mobile couriers to maintain connectivity and delay constraints between integrated relay/reader nodes and their access points. An SDP-based solution conceptualized on Laplacian matrix and λ_2 values was introduced to tackle the guaranteed connectivity objective. The SDP solution presented by URIA minimizes the worst delay experienced between any IN/AP pair.

Our simulation compares URIA against two integrated approaches, DIRSN [8] and ORP [12], which tackle connectivity and delay constraints in vast deployments, respectively. The simulation results show that our URIA excels in handling both objectives in terms of total latency and delivery rates. URIA surpasses its rivals even under higher packet generation and faster topology changing rates. We believe that our solution represents an optimum data delivery approach when both connectivity and delay constraints are demanded for an integrated IoT setting.

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