

A Proposal for Route Selection in IoT Based on the Context of Specific Applications

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Abstract. The term Internet of Things (IoT), basically, means the interconnection of intelligent and addressable devices, allowing autonomy and proactive behavior. The dissemination of data in IoT, usually depends on the application and requires context-aware routing protocols that must have auto-configuration features (which adapt the behavior of the network at runtime, based on contextual information). This article describes an approach to route selection in the IoT for to meet the context of specific Applications. For this purpose, it have suggested four Objective Functions (OFs) for the Routing Protocol for Low-power and Lossy-networks (RPL). Such OFs are dynamically selected based on contextual information. The aforementioned OFs were originated from the fusion of the following metrics: Expected Transmission Count (ETX), Number of Hops (NH) and Energy Consumed (EC). The simulations carried out illustrate that the implemented proposal, when compared to objective functions OF0 and MRHOF, can provide the assurance of data delivery, more energy efficiency and shorter delay when considering contexts of IoT applications.

1. Introduction

The Internet of Things (IoT) is the pervasive presence of a variety of devices, such as: sensors, Radio Frequency Identification (RFID) tags and smartphones, among other devices which can interact with each other for a common purpose [Atzori *et al.*, 2010]. In the scenario of the IoT, plurality is increasing and forecasts indicate that over 40 billion devices will be connected until 2020 [Forbes 2014], allowing for the emergence of new application possibilities, such as: smart cities, health, smart houses, etc.

Among the most promising technologies for the IoT paradigm are RFID and Wireless Sensor Networks (WSN), according to [Atzori *et al.* 2010] and [Sobral *et al.* 2015]. WSNs have limitations on the identification of a person or object in some types

of applications. However, unlike WSNs, RFID systems are unable to sense data from the place in which they are inserted, such as: humidity, temperature and pressure, which are provided by the WSN. This is an indication that the IoT, by means of the integration between the RFID and WSN technologies, maximizes the benefits, thus opening up new perspectives for applications that consider context information, such as: temperature monitoring in remote areas and the air quality of a specific city or region, control of vehicle flow in one way, among others. The context usually refers to location, but it can also cover different information used to characterize entities involved in the interaction between the user and the application. According to [Baldauf *et al.* 2007], context-sensitive systems are able to adapt their behavior to current conditions with no explicit intervention from the user.

In IoT, a number of information, such as features of the device itself, of the environment which surrounds it and of its capacity, can be used as a source of contextual information. This requires context-sensitive routing protocols for the fulfillment of a number of challenges during the exchange of messages in the IoT, such as: a shorter delay, greater reliability on data transmission and minimal power consumption. Based on these challenges, this article proposes an adjustment of the RPL protocol [RFC 6550], which is implemented from the creation of four new OFs. The use of proposed OFs occurs in the process of establishing routes, in order to meet the context of the applications.

The paper is organized as follows. Section 2 sets out the related Works. Section 3 describes the adjustment done on the RPL protocol. The assessment of the proposed approach is discussed in Section 4, followed by the conclusions in Section 5.

2. Related Work

According to [Vasseur, J., *et al.*, 2012], the RPL makes use of metrics specified in RFC 6551 which are suitable for IPv6 over Low power Wireless Personal Area Networks (6LoWPAN) environments, such as: number of hops; latency; delivery ratio, node energy; throughput; level of link quality; and transmission reliability. In [Thubert 2012] a standard objective function called Objective Function Zero (F0) was proposed for the RPL; it was designed to enable interoperability among different implementations of the RPL. The operation of OF0 is simplified and does not use any routing metrics for the definition of the rank. A node chooses as its preferred parent the neighbor within reach which has the lowest rank.

In [Levis & Gnawali 2012], the Minimum Rank with Hysteresis Objective Function (MRHOF) objective function was introduced. MRHOF is only suitable for the metrics specified in RFC 6719. The selection of the favorite “parents” is made taking into account the adopted metrics, where the routes that minimize the cost associated with the metrics are preferable.

[Jayaraman and Delirhaghighi 2013] propose a context-aware approach that alters the functioning of a sensor node based on the phenomena collected from the environment, such as: temperature, humidity, pressure, etc. The contribution of the author, entitled Situation-Aware Adaptation Approach for Energy Conservation in Wireless Sensor Network (SA-A-WSN), aims at monitoring the way the sensor node works in the environment, in order to reduce the network’s power consumption.

According to [Perera *et al.*, 2014] context-sensitive computing has been gaining more market and relevance, to the extent that it is currently being considered to be an important component of the Internet of Things.

A context-sensitive objective function called Context Aware Objective Function (CAOF), proposed by [Sharkawy *et al.* 2014] and aimed at wireless sensor networks, is based on residual resources and on the change in the sensor node's state over time. The function proposed by [Sharkawy *et al.* 2014] performs a weighted sum of the metrics: degree of connectivity of the node, level of power of the battery, and position of the node in the routing tree in relation to the parent node. The ultimate goal of the function proposed by [Sharkawy *et al.* 2014] is to find a probability of delivery to each sensor node.

The use of fuzzy logic to calculate the objective function for the RPL protocol is proposed by [Gaddour *et al.* 2014]. In this work, the objective function is the component used to select the paths by identifying a parent node among many existing nodes. The objective function called QoS-aware fuzzy logic objective function (OF-FL) associates parameters with linguistic variables which are combined with preset fuzzy rules in order to identify the route to be selected. The parameters considered in the OF-FL are hop numbers, end-to-end delay, packet loss rates, and default route change rate.

In [Chen *et al.* 2015] a Scalable Context-Aware Objective Function (SCAOF) Objective Function is proposed; it adapts the RPL protocol to the environmental monitoring within the area of agriculture with a scalable context. The performance of the SCAOF was assessed both in simulation and field testing. The experimental results obtained confirm that the SCAOF can extend the network's service life and improve the Quality of Service (QoS) in the different agriculture-oriented simulation scenarios.

The papers written by authors [Sharkawy *et al.* 2014], [Gaddour *et al.* 2014], and [Chen *et al.* 2015] motivate the authors to propose a new approach for two reasons: *i)* for using metrics which are suitable for 6LoWPAN environments, and *ii)* to perform a weighted average of the metrics to provide quality messaging transmission over a wireless sensor network.

The above-mentioned contributions serve as a basis for the construction of the proposed approach presented in the next section.

3. Proposed Approach

In this article, it propose an approach focused on adaptation of the Routing Protocol for Low-power and Lossy-networks (RPL), [RFC 6550]. The main purpose of this proposal is to optimize routing in order to meet the context requirements of specific applications.

3.1. The RPL Protocol

The RPL protocol is implemented in 4 stages: a) Setup Stage; b) Establishment of Routes Stage; c) Data Communication stage; and d) Path Reconstruction Stage.

In the route Setup Stage, the RPL protocol, in its original version, uses the OF0 to enable the nodes to select the parent nodes (default route), based on information from the rank and on the number of hops of a given node for the sink, as described in expression (1):

$$R(N) = R(P) + rank_{increase} \quad (1)$$

Where:

- $R(N)$, is the node new rank;
- $R(P)$, is the preferred parent rank;

- $rank_{increase}$, is a variation factor (delta) between the node and the parent rank.

3.2. Proposed Approach

Figure 1 illustrates the functioning model of the proposed approach, which is based on the relationship among three nodes. The APPLICATIONS module represents the context of each application. The DATABASE module contains the objective functions which will be used for generating routes that meet the requirements of each application. Four objective functions to be used during the establishment of routes stage were proposed: DQCA-OF1, DQCA-OF2, DQCA-OF3, and DQCA-OF4.

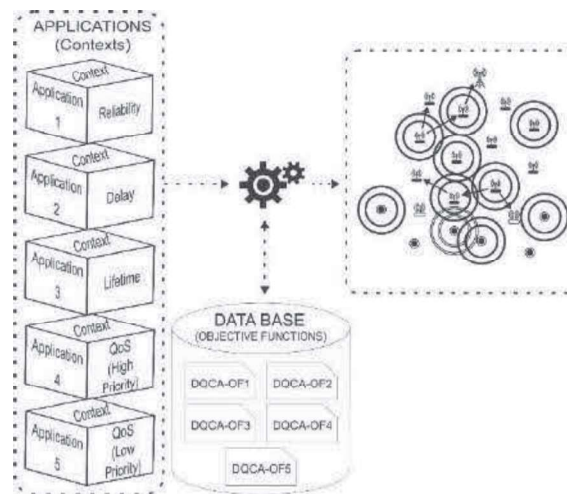


Figure 1. Functional Model of the Proposed Approach.

The objective functions proposed in the approach enable the devices to select the parent nodes (default route) based on the context information obtained from the application. Each application may have requirements that simultaneously need up to three metrics Expected Transmission Count (ETX) and/or Number of Hops (NH) and/or Energy Consumed (EC), which allows us to rate them according to their priority level (N) as (High = 1; Medium = 3; Low = 5). Each of these metrics is represented by an F function. Based on this information, a $T(ni)$ weight is achieved by each network device, which represents the sum of the context functions. Table 1 shows the objective functions used to calculate the route selection.

Table 1. Objective functions used to calculate the route selection

Objective Function	Composition of objective functions	Metrics
DQCA-OF1	$T(ni) = N_{ETX} \cdot F_{ETX}(ni) + N_{NH} \cdot F_{NH}(ni)$ (2)	ETX, NH;
DQCA-OF2	$T(ni) = N_{ETX} \cdot F_{ETX}(ni) + N_{EC} \cdot F_{EC}(ni)$ (3)	ETX, EC;
DQCA-OF3	$T(ni) = N_{NH} \cdot F_{NH}(ni) + N_{EC} \cdot F_{EC}(ni)$ (4)	NH, EC;
DQCA-OF4	$T(ni) = N_{ETX} \cdot F_{ETX}(ni) + N_{NS} \cdot F_{NS}(ni) + N_{EC} \cdot F_{EC}(ni)$ (5)	ETX, NH, EC

The route selection is carried out by applying the value of $T(ni)$ to the route selection mechanism described in expression (6), which enable the nodes to locally decide which route to use for sending the data without incurring the high costs related to the knowledge of the topology of the overall network. The route selection process can

be represented as follows. Consider that $G = (N, L)$ is a directed graph, where N is the set of vertices (devices) and L is the set of non-sorted data (u, v) of elements in N connections. If a message is forwarded by path $C = (v_1, v_2, \dots, v_{k-1}, v_k)$ in a G graph, where v_1, \dots, v_k are vertices and $(l_1, l_2), \dots, (l_{k-1}, l_k)$ are edges, then each node in C has a message delivery cost. Considering that $T(ni)$ is the weight that represents the cost for the delivery of the message from v_i , this means that the $(\sum T(ni))$ for $i = 1, \dots, k - 1$, represents the path quality denoted by Q_C , where:

$$Q_C = \sum_{i=1}^{k-1} T(ni)_{v_i} \quad (6)$$

The rule implemented in the protocol suggests that, the lighter the weight of $T(ni)$, the better the quality of the Q_C path. Thus, the best path to choose is the one which, among all the paths that are available from origin to destination, achieves the lowest value corresponding to the Q_C .

4. Performance Assessment

In order to assess the development of the approach proposed in this paper, it used the COOJA [Osterlind 2006] simulator, which is part of the Contiki simulation environment.

The objective functions proposed herein were assessed and compared with the OF0 and MRHOF functions, which are native objective functions of the RPL. The energy consumption model used for the performance assessment concerning energy was the Energest module from the Contiki [Dunkels *et al.* 2007], which measures the energy consumption within an IoT device.

4.1. Simulation Scenario and Performance Metrics

The scenario for the simulation, which is shown in Figure 2, consists of 11 sensor nodes, 6 tags (RFID), 2 reader nodes (RFID) and 1 sink node. There are 20 devices within a fixed network topology.

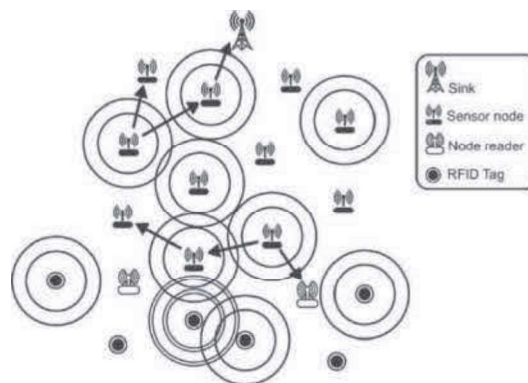


Figure 2. Topology of the scenario used in the study.

The total simulation time was 35 minutes; it repeated the simulation five times, considering that, from the fifth time, no change was observed in the results. However, in order to assess the dynamic change between the objective functions, the time simulated was 140 minutes, because each application lingers for 35 minutes. The messages were simulated with 30-byte packages (default from Contiki). The initial power of the nodes

was adjusted to 200 joules above the Energest energy consumption model from the Contiki [Dunkls *et al.* 2007].

Five metrics used by the RPL [RFC 6551] were chosen for the assessment of the approach: Energy Consumed (EC), Cost of the Reception of Messages (CR), Number of Hops (NH), Delivery Ratio (TX) e Expected Transmission Count (ETX). O Cost of the Reception of Messages (CR) is the ratio between the number of messages received by the sink and the total remaining energy of the network. The Expected Transmission Count (ETX) is equal to the average number of transmissions required (including retransmissions) so that a package is duly delivered to its destination.

Four applications were taken into account for this study. The first application requires priority in reliability (represented by the delivery ratio). The second application requires a shorter delay (represented by the number of hops). The third application requires a long life span (represented by the energy consumed), and the fourth application requires QoS for data delivery (represented by the ETX).

4.2. Results Analysis

The results obtained show that the application that require high priority regarding life span and delay used, among the functions available in the DATABASE, the DQCA-OF4 function for the route selection process. This function was selected because it can forecast, in its structure, the metrics energy consumed and number of hops, allowing for the selection of routes with lower energy consumed and a lower number of hops.

Figure 3 shows that the DQCA-OF4 function achieved, at the end of the simulation, higher remaining energy (approximately 170 joules) when compared to the MRHOF and OF0 objective functions which achieved consumption rates of 100 joules and 80 joules, respectively.

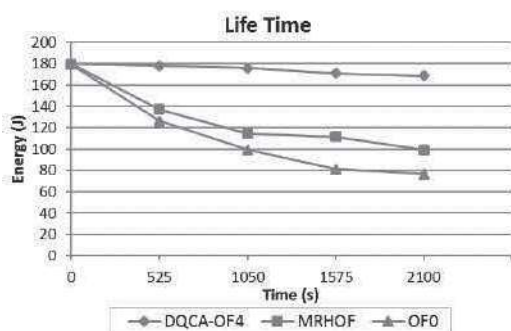


Figure 3. Energy consumption for the network nodes.

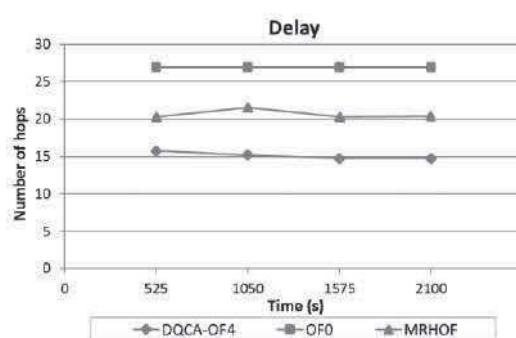


Figure 4. Message delivering delay for the sink.

Also in figure 4, from 525 seconds to the end of the simulation, the DQCA-OF4 function had a shorter delay when compared to the MRHOF and OF0 objective functions. Figure 5 shows that all the objective functions proposed had a lower Cost of the Reception of Messages when compared to the MRHOF and OF0 objective functions. This occurred because the proposed approach uses specific objective functions for each application, which is not the case with the MRHOF and OF0 objective functions.

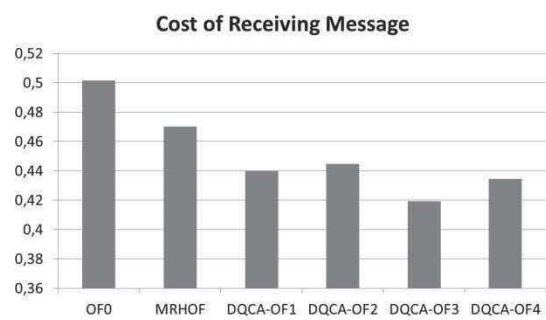


Figure 5. Cost of the Reception of Messages (Number of messages/J).

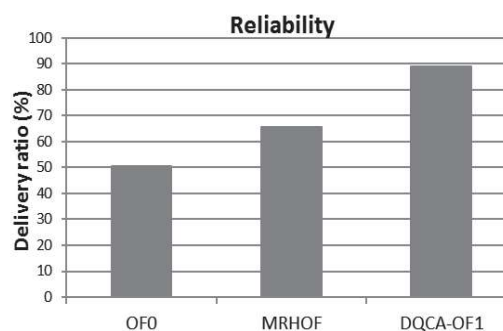


Figure 6. Delivery rate for the sent messages.

For applications that require reliability in the delivery of data, figure 6 shows that the DQCA-OF1 function achieved the best performance, with a delivery ratio of 89% when compared to the MRHOF and OF0 objective functions, which achieved delivery ratios of 65% and 50,4%, respectively. This occurred because, for the selection of routes, the RPL protocol used the function which forecasts the Expected Transmission Count (ETX) and Number of Hops (NH) metrics; in this case, both with high priority.

Figure 7 shows that, for applications that require priority in the quality of the delivery of data, the DQCA-OF2 (EC=High) function achieved the best performance in the number of transmissions/retransmissions with ETX=42 when compared to the DQCA-OF2 (EC=Low) functions, which achieved ETX=88, MRHOF with ETX=140 and OF0 with ETX=180. This difference was achieved because the application required a high level of priority in the Energy consumed (EC) metrics.

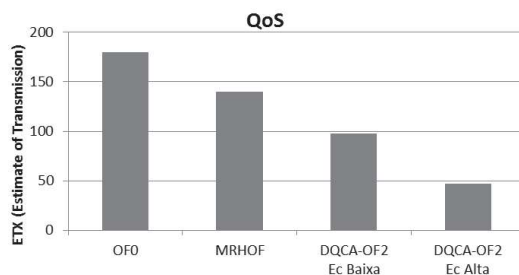


Figure 7. Quality of Service (QoS).

5. Conclusion

This paper proposes an approach for dynamic route selection in IoT based on contextual information of from the applications. The results showed that the proposed approach is more effective when compared to the one used by the RPL protocol in its original version. This was possible because the objective functions which were proposed for the adaptation of the routing in the RPL protocol showed positive results in terms of life span, delay, cost of the reception of messages, reliability, and QoS. Moreover, the route selection mechanism, which was also proposed in this paper, helped in the choice of the highest quality path. Our intention for the next papers is to implement this approach in other protocols which apply to the IoT, taking into account the scalability of the devices that make up an IoT structure.

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