ATP: Adaptive Tuning Protocol for Service Discovery in Internet of Things

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ABSTRACT

Energy is a precious resource in Internet of Things (IoT) especially with battery operated nodes, the overhead that consumes the battery power of the sensor nodes is a fundamental problem. This overhead is mainly caused by the frequent update messages sent to service directories. Although this problem has been investigated in the literature, it is still in its infancy as existing works do not consider the dynamic adjustments of the update messages. To fill in this gap, this paper presents a new adaptive tuning approach between sensor nodes and the resource directory to adjust the frequency of updates based on the battery level of the sensing node. Our protocol works dynamically in both modes, stateless and stateful service registration mechanisms.

Keywords

Service discovery, Resource directory (RD), Wireless sensor networks, CoAP, IoT, Energy-aware.

1. INTRODUCTION

Nowadays, nearly 3 billion devices are connected to Internet, and the researchers predict to reach up to 50 billion by the end of this decade [1]. So, Internet of Things (IoT) accentuates the second era of Internet evolution in terms of gathering information then providing it as services, where the wireless sensor networks (WSNs) play a vital role being the infrastructure for IoT. However, these services cannot be reached with this massive number of sensors unless if there is a mechanism to discover the services. The service discovery paradigms can be categorized into two main categories [2], centralized and distributed. In the centralized approach, all services descriptions that are offered by nodes are saved in an intermediary, called resource directory (RD) which allows the other nodes to lookup for available resources within a respective pre-configured domain by that RD.

On the other hand, nodes in the distributed approach interact directly with each other without an intermediary directory. The directory-based protocols have exclusive functionalities for directory maintenance. In general, any service discovery protocol has four functions (publication, registration (only for the centralized approach), discovery, and resolution). In this paper, we place emphasis on the properties of publication and registration. As for Publication, it is the process that allows devices to announce their offered services, and it can be only used in the distributed approach, i.e. in the absence of service directory. Any publication normally contains six elements, namely Service type or class, Service access, Service name, Domain name, Service properties, and registration. As for the service registration, it is the process of keeping the offered services descriptions in a directory and available to discover and access by authorized devices within a certain domain. The registrat ion can be done in two techniques, Stateful and Stateless. In stateful, the devices are connected directly to the directory, and in this case the location of resources directory (RD) has to be exposed to devices, otherwise the multicast request can be used to find the location of RD. On the other hand, in the stateless technique, the directory RD keeps listening to any announced service by devices and collecting at the same time the service's descriptions from these announcements to update the current services in RD. However, depending only on these announcements is not quite enough to keep RD updated, so sending periodically update messages is very crucial to keep RD coherent and to ensure the awareness of RD about any failure in a real time as shown in Fig.1. Nevertheless, updating RD increases the power consumption of nodes batteries and leads consequently to their failure. So, there is inevitably a trade-off between keeping RD updated by sending the nodes periodically update messages within short intervals which consequently inducing undesirable traffic and more power consumption or expanding these intervals and that put RD in an unawareness position of any failure might be occurred during this long interval as depicted in Fig. 1 and that inconvenience affected cursedly on the reliability of many applications.

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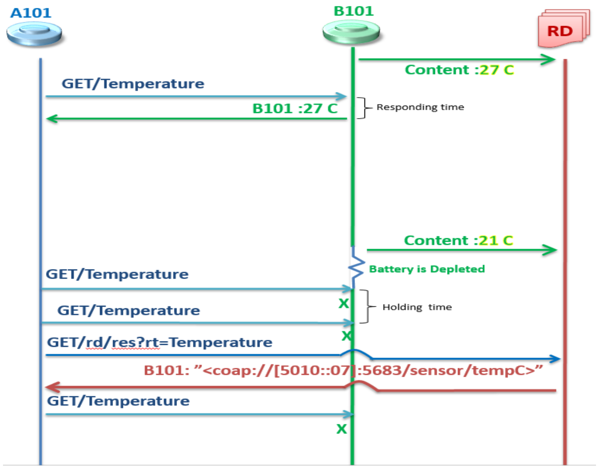

Figure 1. Failure node demonstration

Also, the dead node will keep receiving requests from the other requester nodes according to their last update in RD similar to A101. On top of that, these unanswered requests will dramatically increase the power consumption of the sender nodes which is undesirable in constrained environment. Fig.1 demonstrates clearly the mentioned scenarios [2], where the node B101 battery is depleted without RD notice or A101 either and that's why A101 keep sending requests. To sum up, the service discovery overhead is still a challenging problem which is mainly caused by the frequent update messages sent to service directories. To the best of our knowledge this problem has not been investigated in CoAP, existing works do not consider the dynamic adjustments of the update messages [4], [11-13]. To fill in this gap, this paper presents a new adaptive tuning approach between sensor nodes and the resource directory to adjust the frequency of updates based on the battery level of the sensing node. The rest of this paper is structured as follows. Section II covers the related work and how some protocols tackle a similar problem, section III states the architecture of our protocol, Section IV is the experiments and results part, and finally Section V is the conclusion and future work.

2. Related Work

Saving power in IOT applications is very crucial due to the limited power especially with battery operated nodes, and battery replacement is not usually an option, thus, lifetime should be long enough to enhance the reliability of the network. The previous decade brought a great deal of efforts in terms of energy efficient protocols including those based on the sleep mode functionality, such as new generation of Mica [13]. However, due to the sleep mode and the limitations of sensor's capabilities, it is inapplicable to use the traditional service discovery protocols such as Universal Plug and Play (UPnP) [6] and Service Location Protocol (SLP) [7] in Low-Power Wireless Personal Area Networks (6LoWPANs). Thus, IETF developed IPv6 over 6LoWPANs [22] to reduce the packet overhead and processing requirement which consequently exhausts node's battery power. Following that, IPv6 Routing Protocol for Low Power and Lossy Networks (RPL) [5] which provides a mechanism to minimize energy consumption caused by the overhead resulting from sending control messages to the network layer. Nevertheless, neither RPL nor 6LoWPAN considered the application layer as both are dealing with control packets not data packets which is our issue.

Existing service discovery (SD) protocols for constrained environment show a variety of approaches and can be classified into Non-IP and IP-based protocols [2]. Bluetooth low energy (BLE 4.2) SD is a good example for Non-IP wireless low power protocol, where broadcasting inquires periodically and the connection established once the data transmission is ready. As a result, it consumes up to 20 times less power than a traditional Bluetooth [9]. Regrettably, this approach may not be applicable for all devices and it is only restricted to the devices with Bluetooth. The second example is ZigBee devices discovery which designed only to explore devices within a respective domain using some parameters such as device ID and power source. The mechanism of discovery is relying on a profile called ZigBee Device Profile (ZDP) to optimize the device selection. However, the major drawback of this approach is suitable only for ZigBee network, also it is relying on human's intervention configuration in some cases such as exposing services to IP network [12]. On the other hand, with increasing demand for IP-based SD to the constrained devices IETF standardized the Simple Service Location Protocol (SSLP) for 6LoWPAN [11]. However, the lack of simplicity is the main drawback of this protocol because of the translation agent (TA) between messages and IP network and that leads to more delay. Accordingly, nanoSD has been released to reduce the complexity in lower power networks. However, the problem with this approach is the impact of the wide multicast and broadcast with neighbor nodes [8]. The latest solution is described in [3].

Unlike [4], the proposed protocol is adaptive, i.e., the number of (re)transmissions can be controlled according to the battery's level. In addition, it is flexible since it supports different levels of reliability based on demand. In this paper, we extend the work in [10] by considering the tuning technique but with power levels classifications in the application layer. In general, existing works did not consider the dynamic adjustments of the update messages in service discovery. To fill in this gap, this paper presents a new adaptive tuning approach between sensor nodes and the resource directory to adjust the frequency of updates based on the battery level of the sensing node

3. The proposed ATP protocol

The ATP protocol aims to tune the frequency of service announcement and discovery in WSN by a customization process based on the current node's battery level. Instead of using a default update frequency interval, ATP adjusts this later by varying it to prolong the node's battery lifetime and reduce the overhead. In tuning phase ATP classifies the power level of the node's battery into four levels: high, medium, low, and critical level. We assume that each node is able to discover the RD either by state configuration or by a specific announcement and discovery mechanism. We extend the service description message between the sender node and the RD to include node's current battery level (only at the begging of each level) and the associated service update frequency interval. When the node's battery level changes, a new service description message is announced. The RD can classify the service providers based on their battery and provide rational device assignment. When the node's battery reaches the critical level, the correspondent service description is updated with a new back-up node when the failover is completed, and this will be part of our future work. The threshold is expressed in percentage and can be determined according to the kind of service provided or fixed by the network administrator. For simplicity the thresholds have been assumed respectively 75, 50, 25 and 5. When advertising its services, a sensor node includes the current level in its descriptor. Therefore, a new field of 2 bits can be used for this purpose as shown in table 1. In addition, the node synchronises and tunes the update frequencies with the RD by including the frequency interval that matches its battery level.

TABLE 1: ATP BATTERY'S LEVELS CLASSIFICATION

Level of Power	High	Medium	Low	Critical
battery level %	*b>=75	b>=50	b>=25	b>=5
Bits equivalent	11	10	01	00

*b: battery_level

In high power level when (b>=75) the RD is updated using the default interval (a standard interval). However, in medium level when (b>=50) the protocol slows down the update frequency rate and double the default interval (i.e. double the standard interval).When (b>=25), ATP expands the standard interval to triple (i.e. triple standard interval) and considers this a low level. The last level is the critical level or *failover* level, when *(b>=5)* ATP double the time interval to (*4 standard intervals)*. After that, when (b<5) then battery practically is considered as dead and cannot offer this service anymore. In this case, the service will be transferred to another node (ID, URI if possible), where (4%) of power is quiet enough to deal with a number of emergency quires from specific senders. Fig.3 demonstrates clearly the four possible scenarios that are mentioned early considering the power level.

TABLE 2: EBIT EQUATION PARAMETERS

Parameter Name	Parameter Description
E_{bit}	Energy consumed per bit
Prx_ini	Start-up power consumed in reception
Ptx_e	Power consumption in electronic transmission
Trx_ini	Receiver start-up time
Ptx_out	Output transmit power
Header	Length of packet header
Prx_e	Power consumption in electronic reception
Payload	Length of packet payload
Ptx_ini	Start-up power consumed in Transmission
Trailer	Length of packet trailer
Ttx_ini	Transmitter start-up time
Edecoding	Decoding energy per packet

```
READ battery_level
IF battery_level >=75% then
    WAIT standard_interval then SEND an update of R_info
ELSE IF battery_level >=50% then
    WAIT 2 x (standard_interval) then SEND an update of  R_info
ELSE IF battery_level >=25% then
    WAIT 3 x (standard_interval) then SEND an update of R_info
            ELECT trusted_neighbour
ELSE IF battery_level >=5% then
    WAIT 4 x (standard_interval) then SEND an update of R_info
      Handover to trusted_neighbour
ELSE    SEND: "Due to battery low, the service has been
transferred to another node", ID, URI,
END IF
```

Figure 4. The main rules of ATP

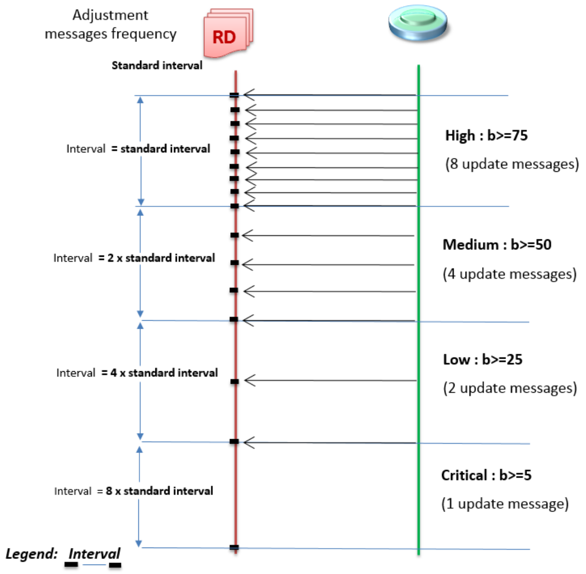

Figure 3. ATP Battery's levels classification

The main rules of the proposed ATP protocol are given in Fig.4.

4. Performance Evaluation

The main objective of ATP is to adjust effectively and dynamically the frequent updates for RD, thus, minimizing the overhead and reducing energy consumption. This section covers the details of the experiments as well as the analysis of the gathered results. To investigate the performance of the proposed ATP, we performed the calculation using C++ to simulate a network behaviour contains upto 500 nodes in terms of battery consumption. Several parameters have been considered in the calculation process as following. *b* battery level of the node at the time of reading which is normally between (0 – 100) %.; *si*: standard interval is the waiting time of each node before sending another periodic update to RD. In addition, *pec* refers to packet energy cost, which is considered as one composite parameter metric for both sleep mode and active mode according to the equation E_{bit} [14] that contains all parameters in table 2.

To evaluate the performance of our protocol, it has been compared with battery lifetime of without levels classification T_w (1). While T_w uses an uncontrolled consumption of power with a fixed standard interval, ATP adjusts the transmitting period by tuning the standard interval using classification mechanism according to the node energy aware. In addition, the dynamic threshold (range) of each battery's level gives ATP another flexibility feature to enhance reliability according to the type of the application, which means each threshold can be maximized or minimized according to the requirements of the application. Generally, the energy consumption of battery is relaying on two parameters: the *voltage V* (volts V) and its *capacity C* (Ampere-hour, Ah), where: *The amount of energy stored in the battery = C×V.* In the ideal case, the amount of energy could be consumed linearly and called linear discharge. On the other hand, experimentally the consumption is not linear as the *recovery effect factor* of the battery plays very important role by allowing the battery to regain part of its lost energy within ideal time, and in this case the battery consumption behavior is not linear and can be called non-linear discharge. Thus, our protocol is considering both cases, the linear and the non-linear discharge.

A. Linear discharge:

We are aiming to prove the gain of our protocol. We mean by the gain here, the amount of power that can be achieved using our protocol comparing to the amount of power consumption without battery level classification T_w,.

$$\mathrm{Tw} = \left\lfloor \frac{b}{pec} \right\rfloor \times si + R_t \tag{1}$$

where: pec>0, and R_t represents the remaining time which will be raised if the rest of the time is less than the standard interval *si,* and in order to avoid any fragment time left behind, we used the flooring function as shown in equation(1), and R_t can be calculated:

$$R_t \overset{\text{mod}}{=} \left\lfloor \frac{b}{pec} \right] \tag{2}$$

While T_w is consuming the battery in one rhythm, our protocol is adapting the *si* tuning according to the battery level, i.e., devoting a specific equation that has been tailored for each level according to Table 1 as follows:

$$\alpha = \left\lfloor \frac{1}{pec} \begin{pmatrix} h + 2(m-h) + 3\big(l-h-(m-h)\big) + \\ 4\Big(c - \big(l-h-(m-h)\big) - h - (m-h)\Big) \end{pmatrix} \right\rfloor \times si + R_t \tag{3}$$

$$\beta = \left\lfloor \frac{\big(2m+3(l-m)+4(c-(l-m)-m)\big)}{pec} \right\rfloor \times si + R_t \tag{4}$$

$$\gamma = \left\lfloor \frac{\big(3l+4(c-l)\big)}{pec} \right\rfloor \times si + R_t \tag{5}$$

$$\delta = \left\lfloor \frac{4c}{pec} \right\rfloor \times si + R_t \tag{6}$$

where *c = b-5*: power at the critical level, *l=b-25*: power at the low level, *m=b-50*: power at the medium level, and *h=b-75*: power at the high level. Thus, these equations (3, 4, 5, and 6) can be gathered in one function (7):

$$f(b) = \begin{cases} \alpha, 75 < b \le 100 \\ \beta, 50 < b \le 75 \\ \gamma, 25 < b \le 50 \\ \delta, 05 < b \le 25 \end{cases}$$

(7)

By running these equations 10,000 times simulating the nodes of network and then dividing by T_w the network gain has been measured and calculated as:

$$Network\ Gain = \frac{\sum_{i=1}^{n} \left(\frac{f(b)}{Tw}\right)_i \times 100}{n} \tag{8}$$

where n represents the number of nodes in the network which is 10,000 in our experiments. Other results have been obtained as shown in Fig.3, when we consider a number of nodes (started with 10% of network nodes) and assigned their power randomly between (0–100)%. Then the number of nodes of this group has been increased gradually up to (90% of network nodes) with a new run, and thus the partial nodes gain calculated as:

$$Partial\ nodes\ Gain = \frac{\sum_{\boldsymbol{i=1}}^{\boldsymbol{pn}} \left(\frac{\boldsymbol{f(b)}}{\boldsymbol{Tw}}\right)_{\boldsymbol{i}} \times 100}{\boldsymbol{pn}} \tag{9}$$

where *pn* represents the partial number of nodes in each turn.
Finally, the average of the two previous gains has been calculated to get more accurate result of the gain.

B. Non-linear discharge:

As a result of the recovery effect factor, the battery depletion is consumed in a nonlinear manner but regains some of its lost energy. Therefore, studying and analyzing this factor has been raised through several battery models such as the analytical model, electrochemical model, electrical-circuit model, and stochastic model. In this paper, we considered the analytical (diffusion) model of Rakhmatov and Vrudhula [15] [16] because it is widely used in the literature and has shown an accuracy in this context. [17]. Briefly, this model demonstrates the diffusion process of the active materials in the battery and predicts the battery lifetime under a certain load. The lost charge includes two parts [17], the first part used by the device (*l*) and the second part is unused and still remaining in the battery (*u*). Similar to the study [15], we inject the nonlinear factor *(u)* in our equations to enhance the accuracy. Similarly, in T_w (1), we injected (*u*) factor as well to become as follows:

$$\mathrm{Tw} = \left\lfloor \frac{(b+u)}{pec} \right\rfloor \times si + R_t \tag{10}$$

$$\alpha = \left\lfloor \frac{1}{pec} \begin{pmatrix} h + 2(m-h) + 3\big(l-h-(m-h)\big) + \\ 4\ \Big(c - \big(l-h-(m-h)\big) - h - (m-h)\Big) + u \end{pmatrix} \right\rfloor \times si + R_t \tag{11}$$

$$\beta = \left\lfloor \frac{\Big(\big(2m+3(l-m)+4(c-(l-m)-m)\big)+u\Big)}{pec} \right\rfloor \times si + R_t \tag{12}$$

$$\gamma = \left\lfloor \frac{\Big(\big(3l+4(c-l)\big)+u\Big)}{pec} \right\rfloor \times si + R_t \tag{13}$$

$$\delta = \left\lfloor \frac{(4c+u)}{pec} \right\rfloor \times si + R_t \tag{14}$$

Gain evaluation:

This subsection represents the evaluation of the gain with respect of using the previous equations. Fig.5 shows the network gain for each battery level classification. We vary the percentage of nodes (started with 10% and ended with 90% of Network nodes) that assigned their power as a high level. Similarly, we did for the others levels to find the gain for each level alone. It can be seen that the best obtained gain was at the low level and the least gain is located in the high level. This is because that the standard interval has been doubled two times in low level, which is not the case in the high level. On the other hand, Fig.6 compares the network gain and the individual node gain with regards to the amount of power in the battery for each level. Fig. 6 clearly shows the best gain between the medium level and the low level.

Another point can be observed, the node with power level less than 5 % is considered dead, and the reason behind that is to save this tiny amount of power to notify RD and any urgent request that this node cannot respond any more due to the low battery. Another point can be concluded, that the gain for the individual node behaves mostly like the network behavior gain except some minor differences.

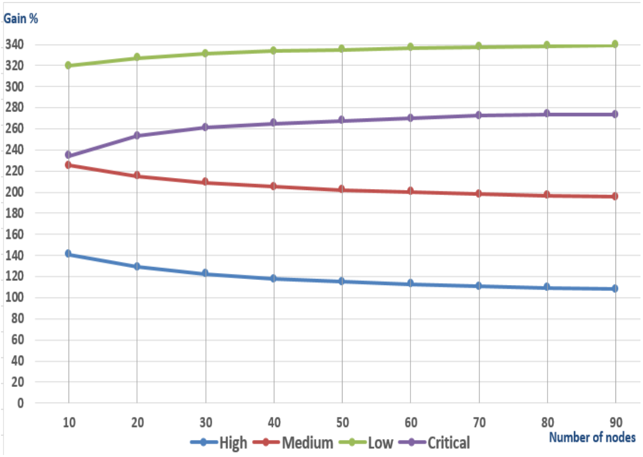

Figure 5: Network gain for each level individually

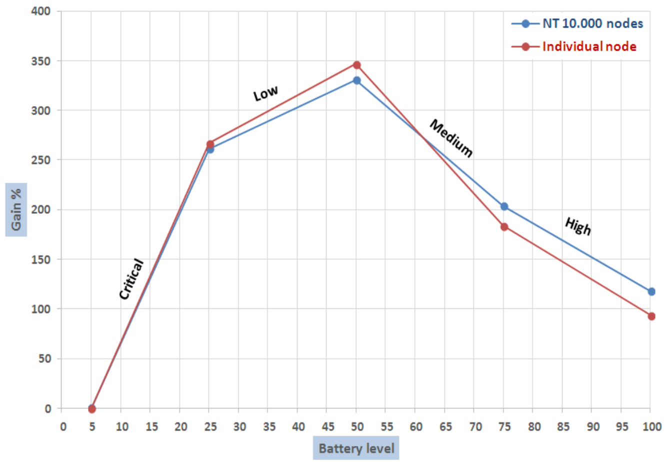

Figure 6: Network gain vs individual node

5. Conclusion and future work

In this paper, we propose an adaptive tuning protocol ATP, for service discovery in WSNs. The proposed protocol can deploys a tuning approach between sensor nodes and the resource directory to adjust the frequency of updates with respect to the energy-awareness of the node. The classification mechanism allows the resource directory RD to be smart enough to make the optimal decision for tuning. However, using more context information can lead to more efficient solutions, and this our future work. We also plan to investigate the handover functionality (i.e. the process of electing trusted neighbour to represent the sensor service and update the services on his behalf for the remaining time until end of service then handover to this recommended neighbour) and then injecting this functionality to ATP protocol. Moreover, our future steps would be towards investigating the performance of ATP under a wide range of operating conditions using both simulation and mathematical models.

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