AFT: Adaptive Fibonacci-based Tuning Protocol for Service and Resource discovery in the Internet of Things

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***Abstract*[1]—This paper explores Adaptive Fibonacci-based Tuning Protocol for Service and Resource discovery in the Internet of Things (AFT). Through using constrained application protocol (CoAP), Internet of Things (IoT) can support Machines to Machines (M2M) communications. CoAP has centralized and distributed operation modes to discover resources. In the centralized mode, resource directory (RD) is used to maintain and host updated services description of each resource in the network. RD requires periodical updates by other nodes. However, regularly updates resulted in additional signaling overhead, drain the node's battery and reduce the overall network lifetime. Hence, the proposed AFT intelligently varies and adjusts the update frequency of the services using Fibonacci sequence. We evaluated the performance using an inclusive experiments' number performed by employing emulated Tmote Sky motes in the COOJA environment. The results prove that the proposed AFT protocol consistently accomplished the lowest control overhead that ultimately increased the energy saving of the resources. They also confirm that this AFT protocol outperforms its traditional counterpart by 75% regarding the overall network lifetime.**

Keywords—Internet of Things (IoT), Fibonacci sequence, Service Discovery (SD), Resource Discovery, Wireless Sensors, CoAP, Energy.

I. INTRODUCTION

Internet of Things (IoT) can be thought of as a network of everyday life objects which have microcontrollers, electronic chips, transceivers and appropriate protocol stack that allow the communication of everyday life objects with end-users as well as with each other, becoming a complementary technology of the Internet [1]. Consequently, IoT aims to improve the internet proliferation through qualifying seamless interaction as well as access to a broad diversity of devices, buildings, controlling sensors, home apparatus, and so on [2]. IoT also aims at providing citizens, organizations, and public administrations by new services through boosting many new applications that use a large amount of data produced by the daily life objects [3].

IoT actually makes application in many various domains such as Smart Cities [23, 24, 25, 26], Smart Homes [27,28], Smart Grids [29,30], Industrial Automation [31] and other domains to make human life's much easier, qualitative, and efficient [4,5]. The adoption and fostering of Internet Protocol (IP) in Wireless Sensor Networks (WSNs) plays a radical function in the IoT vision investigation [6]. These technologies integration has changed the conventional idea of the Internet from the idea of connecting humans to the idea of connecting objects with humans and each other with no limitations [7].

The diversified IoT applications are getting increasing interest from organizations, research, and industrial communities. Furthermore, the utilization of IPv6 protocols within WSNs was standardized by the Internet Engineering Task Force (IETF). As a result, they introduced a new protocol stack (see Figure 1) that is called IPv6 over Low power Wireless Personal Area Networks (6LoWPAN) [8] which guarantees IPv6 datagrams transmission over Low Power Lossy Networks (LLNs) based on IEEE 802.15.4 standard [9]. Nevertheless, using only IP networking protocols in WSNs disallow the prospective of IoT to be quite achieved [32].

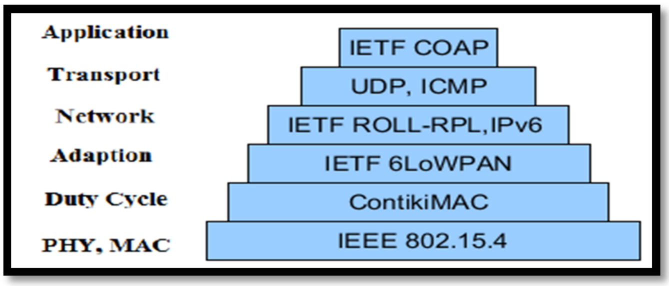

Figure 1. Constrained devices' protocol stack

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Currently, the Hypertext Transfer Protocol (HTTP) is the inferior protocol that web applications rely on in order to transform and access data. The Representational State Transfer (REST) architecture is the base of HTTP [10]. REST fostering in WSNs makes the diffusion and realization of IoT services easier. Nevertheless, it has to be suitable to the limited capabilities resources that describe the LLNs. Normal WSNs nodes are powered by a battery as well as have a few memory kilobytes. They also equipped with limited CPU's processing power, capabilities, and storage [11]. The impact of using HTTP on these resources could be dramatic. The Constrained RESTful Environments (CoRE) which is an IETF working group aims to contribute the standardization and development of the REST architecture in LLNs. They founded a new web application transfer protocol called Constrained Application Protocol (CoAP) [12].

CoAP applies the same application transfer model of HTTP to LLNs, whilst it maintains a soft design as well as less overhead. Hence, CoAP implements some features of HTTP. As mentioned in [13], one of CoAP goals is designing a special requirements web protocol to be employed in constrained environments, considering the constructing automation, energy, and other Machines-to-Machines (M2M) applications that are usually utilized in Smart Cities. These applications can be managed using CoAP web protocol, this increases the importance of web services in people's daily lives. However, CoAP is bound to UDP by default which allows it to be best tailored for the IoT applications because the client and server communicate through connectionless datagram [15].

Generally, CoAP has the centralized and distributed operation modes to discover resources. A unicast request message is used in the distributed mode to discover resources [16]. Moreover, in the centralized mode, resource directory (RD) is used to maintain and host updated services description of each node in the network in a preconfigured area. It also acts as a representative of any network node in order to reply to the service request queries. Moreover, CoAP is a client/server protocol in which the client requests confirmed resources that are previously defined in the Uniform Resource Identifier (URI), after that RD replies with either failure or success message. Interchanging messages in CoAP can be done using an asynchronous method over UDP that needs less energy comparing with HTTP [17].

RD must always be fully updated, so the network nodes must regularly send update messages that include the latest services description such as humidity, light, and so on [18,19]. Nevertheless, the main trade-off of updating RD is the consumption of the network nodes batteries, therefore the node fast failure probability will increase [20]. When trying to decrease the update interval, it would help in maintaining fresh service descriptions in the RD, but it will result in more power consumption of the network nodes. Otherwise, when increasing the updating interval, it will result in antiquated service descriptions and extends the node's battery lifetime.

This paper is divided into five sections as follows: Section II, reviews some work in literature related to the energy saving in IoT. Section III introduces the proposed AFT protocol. While Section IV evaluates the results and shows the experiments. At the end section V, presents the weakness and strength of this work in the conclusion and shows the suggested work in the future.

II. RELATED WORK

Over the past decade, the omnipresent expression Internet of Things (IoT) has gained the attention of both the research departments and the industrial organizations. It is rated that 200 objects per person would be connected and therefore various hundreds of billions of devices. Although IoT proliferation offers too many new opportunities but also afford risks. One of the most important aspects of the IoT, hitherto, is the power consumption of the IoT devices. Therefore, in IoT, power and energy consumption is a crucial problem since IoT devices have bounded power capacity. IoT devices mainly depend on un-rechargeable batteries, hence a number of protocols that were proposed in the literature in order to consume power in IoT applications [33], some of these protocols proposed enhancements on the Network layer especially on RPL. On the other hand, some others proposed enhancements on the Application layer especially on CoAP which is the main concern of this paper.

In 2011, authors in [34], depending on the low radio duty cycle concept, proposed the CoAP protocol and implemented it for the Contiki operating system. Whereas, ContikiMAC low-power duty cycle mechanism was affected by CoAP in order to extend more power efficiency. In their implementation, the advantage of Contiki REST layer was taken, the block-wise transfer was supported, and the separate response mechanism was optimized by configuring the response with new message ID and new type. Moreover, this study provides Contiki REST engine with some macros in order to realize the RESTful web service resources. Many experiments were done with multi-hop networks as an evaluation for this implementation. The main finding of this study shows that low radio duty cycle is a significant factor in improving power consumption but with high latency.

Likewise in 2011, authors in [35], focused on Protocols that are specific to sensor net in which beacons are sent periodically aiming to advertise the nodes neighbor information. However, this beacon transmission is very costly when the power saving mechanism is used within radio duty cycle. Thus they in [35] announced a new layer to overcome this problem in sensor net. To reduce the transmission cost, they assumed that piggybacking several beacons in one transmission, hence the total number of the transmissions will also be reduced. Both pull and push operations were used in this new proposed layer, where the pull operation was used by the network nodes themselves to get announcement information from nodes neighbors and the push operation was used by the network protocols to allow them to announce required information. Moreover, this announcement layer was implemented in the Contiki operating system. An improvement in the performance of the sensor net protocols resulted from using this new layer. Reducing the power consumption also resulted from this new layer usage.

Alternatively, in 2011, the paper in [36] compared HTTP protocol as well as CoAP protocol using several simple experiments from the power consumption aspect. The findings of this study show that packet overhead compression as well as using UDP increases the node lifetime and therefore decreases the power consumption in the whole network. Then, Ostermaier et al., in [37], used the programmable low power Wi-Fi modules in connecting devices with each other and with the internet replacing the use of radio technologies for low power protocols such as CoAP, IEEE 802.15.4 and 6LoWPAN. This approach results imply that using programmable low power Wi-Fi modules expands the lifetime of the sensor battery regardless of using HTTP over TCP/IP for communication.

Correspondingly, in [38], the authors compared CoAP protocol using RPL in Contiki with CoAP protocol using LPL in TinyOS. In this study experiments, the network nodes were powered using batteries. This study results presented that when LPL is labeled, the voltage of the battery reduces by 7% comparing with the original voltage. On the other hand, when preventing the usage of LPL within the experiments, the battery voltage reduces by 30%. Furthermore, Leone et al., in [39], designed new caching architecture to reduce the superfluous communications and to increase the network adaption to the application requirements. Mainly, this approach aims at caching information and thus reducing the overhead of signaling. Consequently, the overall lifetime of the network will be increased. The CoAP-HTTP proxy was used in order to evaluate this proposed work. The findings from this work experiments were using the caching architecture increases the power saving as well as plays an essential role in prolonging the overall lifetime of the network.

A new architecture was proposed by researchers in [40], for mobile cloud sensor application that is based on IoT. Low-power sensors are the main components of this architecture that communicate with each other by using the standard profile as well as protocols based on Bluetooth technologies. Services can be accessed from both the internet and the local sensor cloud of user based on CoAP protocol and Service-Oriented Architecture (SOA). In this study, services can be performed on sensor nodes, as well as the users can use their mobiles and the internet to transform information. The results of this work experiments confirm that it has a significant use in the applications that have a high mobility level as well as have a low-power consumption.

In 2014, the author in [42] suggested a new Trend-based Service Discovery Protocol (TRENDY), which is a context-aware adaptive protocol with the awareness of IoT. This protocol focuses on constrained networks such as 6LoWPAN. It was implemented based on CoAP protocol. This protocol service selection algorithm can collect and rationally employs the context information in selecting suitable service for the user application which depends on the obtainable context information of services and users. This protocol also introduces a new timer algorithm that aims at minimizing the status maintenance control overhead, that leads to reducing the power consumption. The results analysis advocates the performance gain benefits for all the techniques that were used in [42].

In 2015, Mamoun et al. in [41] suggested a new CoAP implementation in which the implementation was done on the centralized method of resource discovery (RD). In this approach, nodes regularly send updating messages with the latest status of their futures to the RD. A fixed period of time was proposed where after it the update messages are transmitted by all network nodes that results in more power consumption and then the battery will be drained. In which a dynamic solution was suggested for the update messages operation in CoAP protocol. It depends on the sending node battery level. The suggested algorithm increases the updating period while the battery level decreases. When the update interval is increased, the signal overhead will be reduced and therefore the power consumption in network nodes will be improved but the data refreshment, in this case, will be affected and the data will be outdated. In this approach, the battery level of the sending node was divided into four main levels; high, medium, low, and critical. To represent the level of the battery, a two bit was used and included in the updating messages. The results show that this work extended the battery lifetime of sending nodes by 10%, as well as it can reach up to 15% when the hops-number between RD and the sending node is 3-4 with regard to the whole network lifetime.

III. The proposed AFT Protocol

The proposed AFT protocol aims at tuning the update messages' frequency in centralized CoAP depending on the battery level of the sender node which is called the Service Agent (SA). Instead of using fixed intervals for updating messages, the battery level was used as the main criteria to increase the intervals dynamically. Thus the next update interval is calculated using the corresponding Fibonacci sequence. This adaptively varies the update intervals and decreases control packets number from the SA's. Therefore, the traffic will be reduced and other nodes, in multi-hop networks, will be benefited. We assumed that each SA has the ability to discover the RD either by using a particular discovery mechanism or by state configuration. Mathematically, Fibonacci series is the sequence of numbers starting with 0, then 1, and each number larger than one equals to the sum of the previous two numbers. This is described by the following equation:

$$f_0 = 0$$
$$f_1 = 1 \qquad (1)$$
$$f_n = f_{n-1} + f_{n-2}$$

Hence, whenever the SA's battery level changes, a new interval will be considered according to the Fibonacci sequence. Having known the SA's battery level, on interval change the RD can re-assign services to the SAs in an intellectual manner.

Algorithm 1 is followed by each SA when sending any status update packet. This algorithm ensures that the SA_interval_counter is less than the max_interval_counter that is allowed and previously defined according to the battery-aware counter. Then according to this counter, the corresponding SA_interval is calculated from the Fibonacci function and it set to the return value from this function so as the counter increases the returned interval value will be increased. This algorithm also ensures that no more one change is done through each time interval.

Algorithm 3: SA on sending an update message

```
if !interval_counter_change then
    if SA_interval_counter < max_interval_counter then
        // the increment according to the battery consumption
        SA_interval_counter = SA_interval_counter + [0,1]
        SA_interval ← FIB(SA_interval_counter)
        interval_counter_change ← 1
    end
end

function FIB(counter)
if counter == 0 || counter == 1 then
    return counter
end
else
    return Fib(counter -1)+ Fib(counter -2)
end
end function
```

Whereas

- Battery_aware_max_counter_limit: this is a global counter for the maximum value that is used as an upper limit for the Max_interval_counter
- Max_interval_counter: an upper limit counter for each individual SA that is registered in RD. This value cannot be exceeded then the Battery_aware_max_counter_limit.
- Interval_counter_change: it is a flag value that is used to make sure that no multiple changes are done through one interval.
- SA_interval_counter: it is the counter value for the interval of each SA registered in RD. this value should never overcome the Max_interval_counter.

Figure 2. Shows the AFT resource discovery protocol in an example scenario. In this example the Service Agent (SA1) at the start send the registration message in order to register its service in the RD. Then the battery level will be calculated at the SA and it will start by full battery. When sending updating messages, the battery level will decrease and therefore the corresponding Fibonacci interval will keep increasing until the battery level will reach to 5% because 4% is the lowest battery level with which the Sky mote can convert to the sleeping mode according to [18]. Thus, at this level the SA will start sleeping mode and its service will transform to another available SA in the network.

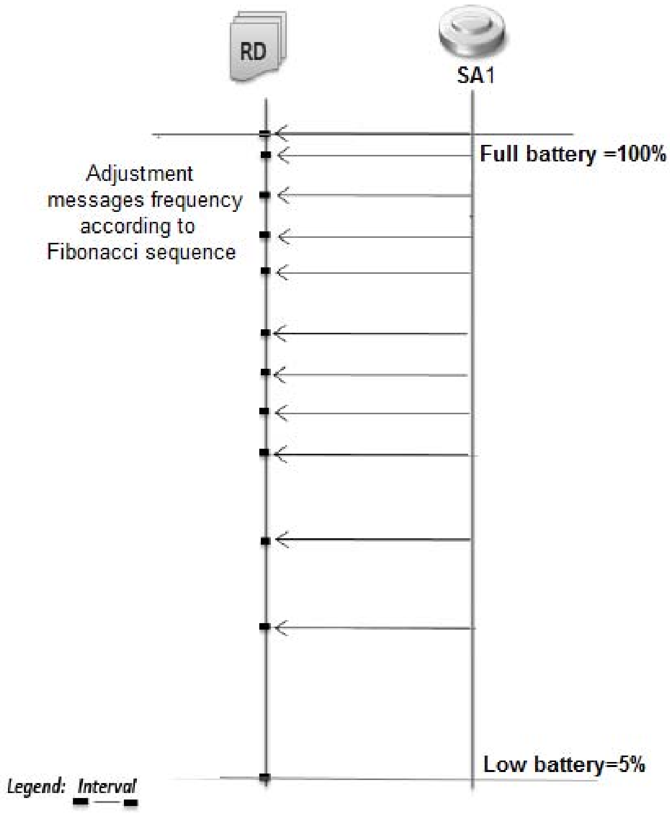

Figure 2. The proposed AFT resource discovery protocol in an example scenario

IV. EXPERIMENTS AND RESULTS

The selection of suitable technologies for the experiments has a major role to perform useful and efficient experiments. CONTIKI [44] operating system (OS) was employed in this paper experiments for the devices. It is an open source OS for IoT. Whereas, it is one of the most suitable OS for low-power Internet communication. Moreover, COOJA [44] is a novel simulator that can be used with ContikiOS. It was used because it provides small as well as large networks of Contiki motes. It also allows them to be simulated. It allows these Contiki motes to be emulated at both the hardware level and at the detailed level. Furthermore, it allows the simulation of larger networks at the detailed level. The simulation parameters that were used in this paper can be summarized in Table 1.

Parameters	Values
Operating System	CONTIKI 3.0
Simulator	COOJA
Nodes Type	Tmote Sky
Physical topologies	1,2,3,4,5 (see section 4.3)
MAC/adaptation layer	ContikiMAC/ 6LowPAN
Routing Protocol	RPL
Radio Environment	Unit Disk Graph Medium (UDGM)
Nodes count	5-320 + RD node
Simulation Duration	Variable
Full Battery	7000 mJ
Transmission Range	50 m

Because it is difficult to get the SA battery level directly from Cooja in order to specify the amount of power remaining for any SA, we calculated the consumption of the power for each SA by using the *energest* pre-defined function in ContikiOS. After that, the residual energy was calculated using the next equation (2) in order to get the battery level.

$$Residual\ power = Battery - overall\ power\ consumption \quad (2)$$

Referring to the hardware, all the nodes in the experiments had the same hardware. We used Tmote Sky with MSP430 microcontroller because it is the most popular module and widely used in WSN. All the Sky motes batteries was calculated taking into consideration all the factors that influence the battery charging level such as the power consumption that caused by the MSP430 microcontroller in various modes, radio transmitting and radio receiving power.

The results in Figure. 3 shows the relation between the battery level and the time in seconds using ellipse topology. The adaptive tuning protocol proposed by [41] starts to save energy at battery level 75%.Whereas, the overall energy saving, when the adaptive tuning protocol proposed by [41] is used, extends the network lifetime by 15%. The lifetime of the network was calculated based on the average of all nodes to sleep where each node lifetime was calculated from the start of sending update messages to the RD until the battery level reaches 5% because as we mentioned before this is the lowest battery level with which the Tmote Sky can convert to the sleeping mode [18]. Moreover, when the AFT protocol is used, saving the energy starts at level 95%. Therefore, AFT protocol outperforms both the adaptive tuning approach and the standard approach since it extends the network lifetime by 75%.

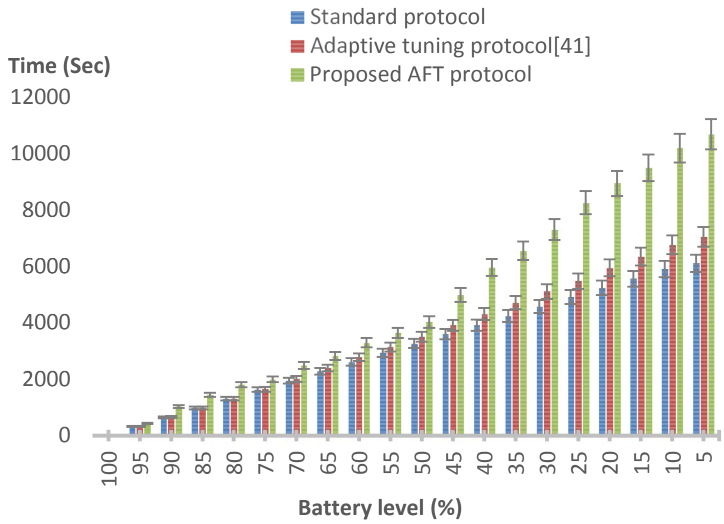

Figure. 3 Network lifetime in various battery levels for the three protocols using the ellipse topology

V. CONCLUSION

This work aims to improve services update operations to the RD using a new proposed AFT protocol. The main goal of this proposed AFT protocol is to keep the RD regularly fully updated with messages that contain the latest status of associated services (i.e. light, pressure... etc.). Static update intervals in CoAP's RD make the update operations inefficient in many cases. Hence, the proposed AFT protocol overcomes this problem by using Fibonacci-based tuning algorithm in which the update intervals will be varied according to the corresponding Fibonacci sequence number depending on the SA battery level. This paper reduces the power consumption in the network nodes (SA) by varying the updating intervals. Therefore, the network nodes batteries will be extended and the whole network lifetime will be prolonged. However, the freshness of the data still needs to improve. The results show that this AFT protocol outperforms its traditional counterpart by 75% regarding the total network lifetime. In future, we are planning to overcome the weakness of the AFT protocol by improving the freshness of the data so that the RD will always have the latest status of the services.

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