# CoAP-based Healthcare Sensors Network: a survey

Hasan Ali Khattak, Michele Ruta, Eugenio Di Sciascio
DEI - Politecnico di Bari
Via Re David 200, I-70125, Bari, Italy
hasan.alikhattak@deemail.poliba.it, {m.ruta, disciascio}@poliba.it

***Abstract*— The Internet of Things (IoT) vision is a hot research topic which enables all kinds of devices to connect together and share information seamlessly. IEEE 802.15.4 Low power Wireless Personal Area Networks (LoWPAN) and IPv6 over LoWPAN (IETF 6LoWPAN) defines standards and protocols for resource constrained Wireless Sensor Networks (WSN). Constrained Application Protocol (CoAP) is an emerging application layer protocol supporting resource constrained devices and easy integration with the existing TCP/IP standards. It is particularly useful for advanced applications in the healthcare field. This paper surveys technologies and techniques for using CoAP-based WSN for connecting and monitoring medical sensors. Application requirements for creating healthcare WSNs utilizing IPv6 and CoAP and real-time monitoring issues are also discussed.**

**Keywords—WSN, CoAP, Healthcare, Internet of Things**

## I. Introduction

In foreseeable future many everyday objects around us would act pro-actively not only to consume but also to generate information. Most of these objects would have resource constrained sensors of different kinds, which will help in achieving new frontiers in several sectors such as logistics, domotics, entertainment, agriculture and health-care. Internet of Things [1] concept has captured much attention due to its ability of seamless integration of objects, which are becoming embedded with sensors and gaining the ability to communicate into the Internet.

The *Internet of Things initiative*, an EU framework project for research & development and standardization through different pilot projects, has declared Internet of Things as one of the important areas for the future Internet, with high potential for positive impact on European social and economic perspectives [2]. Internet of Everything is expected to generate US$613bn of global profits in 2013 alone [3], currently the number of connected devices to Internet is 13 billion which is 2 times the world population and finally the same white paper predicts that there will be approximately 25 billion devices connected to the Internet by 2015 and 50 billion by 2020. The Internet of Things has been termed as one of the six most disruptive civil technologies which would have potential impacts on US Interests to 2025[4].

Several applications of the IoT are possible and a large array of adoption fields is expected in the next few years. One of the most promising application domains is considered to the healthcare domain. All the IoT features have a relevant and undoubted interest in the healthcare. E-healthcare information systems include applications for tele-medicine, tele-health, and tele-homecare services. Wireless Sensor Networks have significant impact on healthcare systems as they allow disseminating information sources in a pervasive way to improve monitoring capabilities and decision support. Obviously, several aspects have to be taken into account in this kind of applications, where unobtrusive and transparent technology inclusion is strongly required.

This paper proposes a survey of most common technologies for a wireless sensor networks devoted to implement a healthcare monitoring system. Basically, the investigated WSN infrastructure comprises the exploitation of the Constrained Application Protocol (CoAP) [5] to accomplish the following goals:

- To model healthcare related sensor properties as resources and expose them to the WSN clients.
- To manage sensor resources using basic HTTP methods with a RESTful approach which should be monitored using a traditional web browser.

Consider that, among several alternatives proposed to define protocols for object networks, 6LoWPAN [6] at network layer and the CoAP at the application are emerging as promising widespread standards. Particularly, the architecture surveyed in the present paper includes a Telos sensor [7] interfaced to Pulse Oximeter [8] and EKG [9] capable of measuring body temperature, oxygen saturation, and heart rate of a patient. It will be used as reference testbed.

The rest of the paper is organized as follows: in Section II we provide a brief synopsis of the current state of the art for Wireless Sensor Networks while Section III gives an overview of suitable protocols for WSN emphasizing the role of CoAP. Furthermore, Section IV surveys the implemented Internet of Things testbed evidencing as proper wireless sensors and a CoAP-based infrastructure can allow to deploy a self-contained advanced healthcare sensor network. Finally Section V gives insight on the conclusion and future work.

## II. Related Work

Wireless Sensor Networks have been of considerable interest to many researchers due to the fact that they have many potential real world applications. Sensors can collectively observe various phenomena in any large area by simply setting the appropriate network topology. Each of the sensors is able to communicate with other nodes using its networking capabilities while the WSN collective potential is dependent upon optimal and reliable communication of the events captured by the individual sensors. Wireless Sensor Networks promise great flexibility, low cost, have small hardware requirements and thus low power consumption. Several network topologies are supported and multi-hop transmission grant scalability for building dynamic networks. Possible applications range from structural monitoring, weather observation, patient health supervision, agricultural measurements and industrial control & monitoring [10]. Significant work has been done for defining appropriate topologies to take advantage of the full potential of wireless sensor networks [11]. Deploying a WSN has many challenges due to the resource-constrained nature of the involved devices. Among the issues for setting-up a proper infrastructure, the design of communication and application protocols to provide end to end connectivity and management of the whole network is surely prevalent.

CoAP is a protocol similar to HTTP devoted to interconnect objects, exploiting a binary data representation and a subset of HTTP methods. It follows the REST (Representational State Transfer) paradigm for making data and resources accessible. Analogously, 6LoWPAN is a protocol for WSNs defined to enable IPv6 packets to be carried on top of low power wireless networks, specifically exploiting IEEE 802.15.4 protocol. Both 6LoWPAN and CoAP use UDP for data transport, as TCP is considered too resource-consuming. 6LoWPAN can be interfaced to IPv6 and CoAP/UDP to HTTP/TCP, so that sensor data can be accessed from the Web. Particularly CoAP is assuming relevance for its lightweight impact on storage and computation, resulting useful for a variety of application domains [12].

Typically Wireless Sensor Networks only include homogeneous sensors and are application-dependent and engineering-oriented. This is a strong limit in terms of interoperability and in sight of the integration in large-scale complex architectures. This is particularly true in case of healthcare applications. One of the major goals of healthcare monitoring systems is to reduce work load on healthcare providers for measurements and also to ease the patients with quick response in case of emergency. The requirements of a healthcare sensor network greatly depend upon the specific application and deployment environment. The integration of most common pervasive computing technologies such as communications protocols and wireless sensor networks is leading to innovative applications in the tele-medicine area, particularly for ubiquitous persistent monitoring of elderly or disabled people [13], as well as for patient follow-up during rehabilitation phase [14]. Context-awareness is the key aspect of such approaches to improve quality of healthcare services.

There has been several work aimed to develop solutions for patient monitoring, for example Project Code Blue [15] which proposed a wireless infrastructure for emergency situations where sensors and PDAs needed to be integrated in the code blue framework. The project was undoubtedly advanced but there was lack of focus on interoperability and also it lacked a possibility to seamless integrate the system with the Internet so that a remote monitoring of patients at home could be carried out.

Analogous case is the u-Healthcare SensorGrid [16] project developed by AJOU University. Deep integration of Internet services with the proposed system also lacked, in spite of it is vital for remote patient monitoring.

A sensor network defined for a hospital, where the infrastructure is fixed and fully powered, will be quite different from the one designed for home-based patient monitoring where the patient is remote. This second case requires a more pervasive and unobtrusive approach to control sick people. Hence, there have been different studies and proposals for patient monitoring at hospital such as in [17] and, on the contrary, at home for personal monitoring as in [18]. Nevertheless, a shared goal to produce an interoperable system adopting open standards for healthcare (such as for example HL7 [19]) and a seamless framework to be easily deployed in any given scenario is still missing.

## III. Technological Background

In what follows most relevant technological details are surveyed related to both network and application protocol underlying a wireless sensor network for healthcare monitoring purposes.

### *A. IEEE 802.15.4-LoWPAN*

The peculiarity of wireless sensor networks is in enabling machine-to-machine communications rather than present human-to-human communication oriented network technologies. Particularly, the wireless standard IEEE 802.15.4, also known as LoWPAN [20], has been identified as a potential candidate to be used in healthcare applications as it is specifically targeted to body area sensor networks. LoWPAN specifies physical layer and media access control (MAC) layer for Low-rate Wireless Personal Area Networks (LoWPAN) deployed using resource constrained devices. Components belonging to the LoWPAN typically work together to connect a given physical environment to their virtual counterpart for real world applications. Common topologies supported by LoWPAN include star, mesh and also combinations of them. Other important features include real-time suitability by reservation of guaranteed time slots, collision avoidance through CSMA/CA and an integrated support for secure communications. LoWPAN-based constrained devices are also enabled to have power management functions such as link quality detection and energy consumption monitoring.

The physical layer of LoWPAN is responsible for the following functionalities:

- Data transmission services (transmission and reception).
- Physical layer management entity (performing channel selection and energy and signal management functions).
- Layer management function to activate and deactivate the transceiver.

The Media Access Control (MAC) sub layer is responsible for the following functionalities:

- Data service for transmission of MAC frames through the physical layer.
- Management interface for accessing physical channel and network beaconing.
- Other services such as frame validation, guaranteed time slots provision and handling of node associations.
- Security related functionalities which can be utilized by upper layers to provide secure communication by using symmetric cryptography and access control lists.

IEEE 802.15.4e is chartered to define a MAC amendment to the existing standard 802.15.4 which adopts channel hopping strategy to improve support for robustness against external interference and persistent multi-path fading.

### *B. IPv6 over IEEE 802.15.4*

IETF 6LoWPAN [6] enables resource constrained devices using LoWPAN to connect to the Internet backbone using IPv6 [21]. IPv6 offers address space enough to overcome the addressing problems for such huge number of micro-devices. IETF working group 6LoWPAN has defined specifications to support transport of IPv6 datagrams in LoWPAN. UDP is exploited as reference transport protocol. Apart from the large address space, IPv6 also provides the following benefits:

- Reuse of the existing application layer protocols.
- Seamless end-to-end integration with existing Internet infrastructure.
- Stateless auto configuration and programmability using the socket APIs commonly available.

There are several challenges in transmitting IPv6 packets over LoWPAN links [11]; among others, IETF RFC 6282 overcomes the difference between IPv6 Maximum Transmission Unit (MTU) which is 1280 bytes and the maximum frame which is 127 bytes long by defining an *adaptation format* which provides the following functionalities:

- Fragmentation and reassembly of large IPv6 MTUs by using additional headers. They enable the transmission in 802.15.4 frames.
- Storage of datagram size, datagram offset as well as datagram tag to help in reassembly.
- Data compression. Compacting techniques are used to increase the payload size of upper layers of IP stack.

Finally, in scenarios such as mesh routing, the sender and receiver may not be connected directly, therefore the LoWPAN packet header carries link layer addresses along with hop count.

### *C. Constrained Application Protocol (CoAP)*

IETF Constrained Application Protocol (CoAP) [5] has been designed specifically to take care of machine-to-machine communication needs. CoAP is an open application layer protocol conforming to the REST architecture, while providing asynchronous communications, resource discovery, resource identification as well as HTTP to CoAP and CoAP to HTTP translations. CoAP provides reliable message exchange using REST architecture for CoAP client and server used for application development as shown in Figure 1.

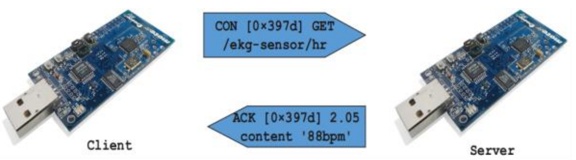


Figure 1 CoAP-based Client/Server interaction

CoAP messages are encoded in a binary format consisting of 4 bytes header followed by optional data and payload. Noteworthy is the adoption of 6LoWPAN adaptation layer which enables the reusability of TCP/IP protocol suite for a seamless integration with the present Internet infrastructure.

In a typical CoAP protocol stack, resources are identified using a hierarchical Uniform Resource Identifier (URI) schema by the server node. On the other hand, clients access these resources via short UDP messages using basic CoAP methods specified in the Request Header which includes the "`CODE`" field that determines what specific methods (`GET`, `PUT`, `POST`, `or DELETE`) is required. Upon receiving a CoAP request, the client sends a response messages structured in a status code followed by a phrase (such as for example `404 NOT FOUND` and `503 SERVICE UNAVAILABLE`) depending upon the request and availability of resources. `Message ID` is used for duplicate detection while the "`Type`" field is used to differentiate between four different kinds of messages that include:

`[CON]` Confirmable reliable transmissions

`[NON]` Non-conformable/unacknowledged requests

`[ACK]` Acknowledgments

`[RST]` Reset

In CoAP-based WSNs each sensor acts as a server node exposing a `/.well-known/core` resource path for resource discovery by other clients. A client can access this path with POST method to register its own resource or with GET to discover the already registered resources. The `Observe` option when passed with `GET` allows the clients to register to a resource so that in case of any update the server will notify the client asynchronously. For example, a hearth rate monitoring sensor (hrs) is exposed at `coap://server/oximeter/hrs`. The client will issue a GET request with `uri-host=server` and `uri-path=/oximeter/hrs`. In response the client will receive the payload which may include the beats per minute and in future if there is a change it will be notified to the client. Similarly `POST` modifies a new resource or updates an existing one, `PUT` creates or overwrites a new one and `DELETE` will remove the specified resource from the server.

Simple Network Management Protocol (SNMP) [22] is a standard for managing devices over IP networks. It has been used for a long time and is comparable to CoAP because of the similar set of protocol operations. Although SNMP was designed before the advent of low powered devices, there have been some research work on enabling SNMP for resource constrained devices, but certain features such as the optimized resource discovery and low memory footprints are only featured in CoAP.

For a comparison between CoAP and SNMP it can be seen the Table I. In general CoAP becomes very competitive from the memory exploitation standpoint. For example, to store 3 novel resources under /.well-known/core, CoAP requires less than 1.0KB of additional ROM and 100B of RAM.

## IV. Wireless Sensor Networks for Healthcare

Wireless sensor networks are among the pioneers in data collection infrastructures, especially in real-time scenarios such as the healthcare ones. By interconnecting

TABLE I.
COMPARISON BETWEEN SNMP AND COAP MESSAGING FORMATS

| **Features** | **SNMP** | **CoAP** |
|---|---|---|
| Format | MIBs | Binary(JSON) |
| Identification | OID | URI |
| Request | GetNext, GetBulk | GET |
| Update | SetRequest, (no equivalent) | POST-PUT, DELETE |
| Asyn. Comm | InformRequest | OBSERVE |
| Discovery | SNMP Walk | core-link-format |
| Memory | ROM : 32.2K<br>RAM : 0.2K | ROM: 8.5K<br>RAM: 1.5K |

a wide range of resource constrained devices it is possible an easier gathering and transmission of medical data.

This section is devoted to show how such kind of systems can be set-up in a very simple way. The architecture proposed as an example is shown in Figure 2, where healthcare sensors are interfaced to a Oximeter and an EKG sensors programmed using a proper REST engine. The obtained sensor network is connected to the monitoring nodes through a CoAP proxy providing the interface between toward HTTP web servers for data storage.

Doctors or physicians can use the monitoring CoAP clients to access the data in real-time. The deployment has been tested initially in the COOJA simulator which is integrated with the Contiki-OS (see later on for further details).

### A. *Reference Architecture*

Contiki-OS is an open source operating system for the Internet of Things, consisting of tiny, battery operated low power systems. Contiki supports standard IPv6 as well as IPv4 along with low power wireless standards such as: 6LoWPAN, RPL (IPv6 Routing Protocol for Low-Power and Lossy Networks), and CoAP. Contiki-OS also has support for SNMP [23] through Contiki-SNMP.

ContikiMAC and sleepy routers along with 6LoWPAN IPv6 stack offers memory efficient implementation of TCP/UDP, IP and ICMP (Internet Control Message Protocol) standards. IPv6 routing is supported by ContikiRPL as specified in IETF RFC 6550. There have been studies [25] which show the interoperability of IPv6 with BLIP in TinyOS (UC Berkeley has released an Open Source implementation of IPv6 running on TinyOS 2.x called BLIP, Berkeley Low-power Internet Protocol) and IPv6 in Contiki through TinyRPL and ContikiRPL respectively.

The wireless sensor network adopted as testbed for the present paper is based on components specifically targeted to healthcare applications. Particularly, Telos mote sensors have been exploited, including a pulse oximeter and an EKG gauge (as shown in Figure 1). Consider that Telos mote data sheets are openly available and it is fully supported by Contiki-OS [24].

Within the “toy WSN” used as proof of concept and measurement testbed, the pulse oximeter is used to reliably assess patient vital health metrics Heart Rate (HR) and blood oxygen saturation ($SpO_2$), while the EKG monitor attached to the patient’s chest measures cardiac activity. The sensors perform all of the required calculations and relays vital sign data over a serial line which can be easily interfaced to a mote. The data gathered by these sensors is in raw form and needs to be converted for further calculation and visualization, which is done on a web server as shown in the general architecture sketched in Figure 2.

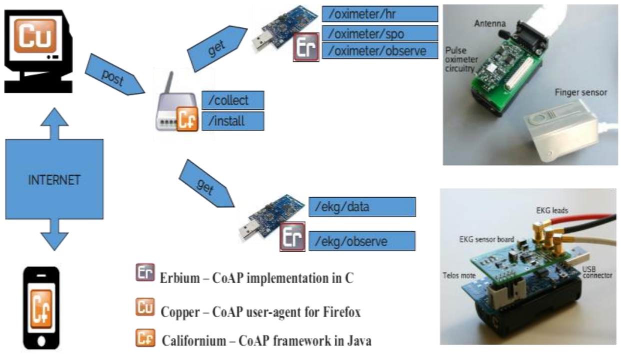


Figure 2 Architecture of the CoAP-based Wireless Sensor Network used as testbed

In order to develop the server-side of the testbed, the Erbium REST engine (Er) [26] has been used, which is a CoAP implementation in C and for the Californium framework (Cf) [27] client for Java. In addition, the monitoring through the web browser is done using Copper (Cu) [28] CoAP user agent for Firefox. The Erbium macro RESOURCE is used to define the resource on each sensor node. For example to define the Heart Rate resource of Pulse Oximeter we define:

```
{RESOURCE(hr, METHOD\GET,"oximeter/hr",
"title= "Oximeter"; rt="oximeter");}
```

When the CoAP client sends a GET request to the server for the uri-path=/oximeter/hr, the hr_hanlder is invoked by the Erbium engine which reads the heart rate value from the sensor and returns it to the client as a response message. This reply can be formatted following the JavaScript Object Notation (JSON) and further processed according to the application requirements.

### B. *Closing Remarks*

The implemented Internet of Things testbed evidences as proper wireless sensors and a CoAP-based infrastructure can allow to deploy a self-contained healthcare monitoring system. A unified hardware and software framework grounds the system enabling applications for patient monitoring in various medical fields. Thanks to data gathered by sensors, the patient information is transmitted in the form of JSON to a Web server where it is stored and after accessed and even processed by medical personnel.

Choosing CoAP gives more advantages w.r.t. competitor technologies including a whole support for TCP/IP protocol stack thus making easy and seamless to integrate the WSN with present Internet infrastructure. In this way a large array of applications can be enabled starting from monitoring the healthcare sensors easily over conventional Internet using traditional browser.

## V. Conclusions And Future Work

This paper shows a practical implementation of CoAP application layer protocol for low-power and low-rate devices in case of patient monitoring. The possibility of being able to use TCP/IP protocol makes such a healthcare sensor networks to be part of Internet of Things. Support for integration with the current Internet infrastructure makes CoAP more viable in comparison to the other approaches described in the literature review.

It must be considered that current solutions only allow a simplistic data-oriented representation of resources and elementary retrieval procedures based on "string matching" between requests and resource attributes, which provide just binary yes/no outcomes. Exact request/resource matches are very uncommon in real-world scenarios with heterogeneous devices, sensors and actuators from several independent providers. Hence, future directions include the support for logic-based matchmaking of meaningful and semantically rich events, device and resource annotations [29].

## Acknowledgments

The authors acknowledge partial support of EU-PO Apulia region FESR 2007-2013 project "UbiCare" - (UBIquitous knowledge-oriented social framework for continuous healthCARE).

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