A Framework for Flexible Sensor Information Dissemination

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Abstract—**The integration of the digital world into every aspect of our lives is becoming more and more preeminent. Nowadays, not only humans but also devices and the environments where we dwell are also able to provide their own information, through the usage of sensors. Through their interconnection over communication networks, sensors enable Ambient Intelligent scenarios achieving a true Internet of Things, and crossing the gap between computer systems and the real world. However, the different sensing devices and information generated by them, are of such disparate nature that it becomes increasingly difficult to access and make use of such heterogeneous data. In this paper, we propose a framework which not only considers a media independent information access to sensors and their supplied data, but is also flexible enough to configure and provide different means to best transport collected sensor information via wireless gateways, facilitating its deployment in different scenarios. We demonstrate its usefulness by providing a throughput efficient approach towards the collection and dissemination of sensing data, through sensing information compression and aggregation of multiple sources.**

Keywords- Media Independent, IoT, M2M, Sensors

I. INTRODUCTION

The evolution of the Internet has allowed the continuous integration of humans and machines into a connected environment. This connectivity has provided access to content and services while on the move, using different access technologies and underlying service platforms. Moreover, this connectivity plane is being extended to encompass devices and surrounding environments, gathering information about their operation and management. This information, obtained from sensors, can be processed as context information, and used as the means to monitor and optimize industrial processes or even for entertainment purposes, shortening the gap between computer systems and the real world. In fact, the logic that operates over this sensing information can enable a plethora of scenarios, empowering the conception of smart environments and mechanisms, where sensing information is used as the driver for the improvement of processes surrounding our everyday lives.

Parallel to this, sensors are becoming widely deployed and start to appear in devices such as our own smartphones, which come coupled with GPS, accelerometers, magnetic compass, pressure and other sensors. The growth on the number of off-the-shelf devices capable of sensing and transmitting information consorts with the need for industrial and personal solutions encompassing a considerable range of different and diverse applications [1]. The increasing demand for such devices has set the way to cheaper and to a very diverse market for sensor networks [2]. Sensor brands such as Sun SPOT, Waspmote, or Iris (and much more) have commoditized the sensor network market. Sensors have became accessible to developers outside the sensor networks community and present a platform ready for software development allowing at the same time, hardware extension. Although this increases the availability of sensing information (which, in the case of smartphones as nodes with communication capabilities, is even able to be remotely sent to processing service platforms) and furthers the concept of Internet of Things, it also denotes the diversity of sensors (which can be of different manufacturers and provide different information). As such, the creation of a true Ambient Intelligence environment where a variety of sensors is able to provide information of different nature and context to support and improve multiple processes should provide some desirable characteristics. On one hand, addressing the operation and information specificities provided by the different sensors should be transparent and not limit deployment or demand complex translation mechanisms. On the other hand, providing that information to consumers should be optimized towards the underlying transport technology, taking into consideration particular requirements which differ when the information is flowing through the sensor network and when it reaches a more powerful infrastructure.

In this paper, we propose a framework, which not only considers a media independent information access to sensors and respective supplied data, but is also flexible enough to configure and provide different means to best transmit collected sensor information via wireless gateways, facilitating its deployment in different scenarios. We demonstrate its usefulness by providing a throughput efficient approach towards the collection and dissemination of sensing data, through sensing information compression and aggregation of multiple sources.

This paper is organized as follows. In Section II we present the state of the art, highlighting information dissemination frameworks and media independent handover services. Because the existing work does not meet the set of proposed goals for a true media independent and flexible sensor information dissemination architecture, we propose our Media

Independent Sensor Framework in Section III, describing its underlying mechanisms for generic sensor access and sensor information dissemination. Section IV presents evaluation of our framework and Section V concludes this paper.

II. State of the Art

The following section provides an overview of related work, considering different frameworks to support information dissemination and media independent mechanisms.

A. Sensor Information Dissemination Frameworks

A critical aspect of smart environment scenarios, where sensor information is generated, is how to forward that information to service processing platforms in a flexible and meaningful way. Not only the sensor nodes can provide widely different information in terms of format and underlying wireless technology, but also the information consumers themselves can have their own specificities for the expected information (e.g., can be part of other processes that wish to encompass sensor information in their processing). Providing access to timely context information provided by sensors relates, in many aspects and objectives, to well established international projects such as Airnet [3], SENSEI [4] and ETSI M2M [5]. Protocols such as [6] and [7] allow nodes to share events relaying information and device status details, but the first sends the information in large XML files, and the second features a specific and static set of parameters in each message. Other approaches, such as [8] and [9], provide examples more directly related to the information sharing mechanisms of sensor networks, but they do not consider event notification nor contemplate flexible means for sensor information consumers to configure and receive that information in a dynamic and scalable way.

B. Media Independent Services

It is common for current mobile terminals to come equipped with different interfaces able to connect to multiple access technologies. This enables scenarios for opportunistic handovers where the data sessions received through one technology can be seamlessly relocated to another more performing technology when available. However, these mobility scenarios need to take into consideration the different specificities of each technology as they try to obtain information about current and candidate link conditions, in order to determine the best handover candidate. Conceiving mobility architectures able to consider and interact with different access technologies has led to complex solutions difficult to deploy. Aiming to facilitate and optimize these handover procedures, the IEEE 802.21 Media Independent Handovers (MIH) standard [10] provides a set of technology abstraction mechanisms able to obtain information and control different access technologies. With these mechanisms, high-level entities are able to collect events on the different link layers, and issue commands to control them, in a media independent way. These heterogeneous capabilities have been extensively used to produce comprehensive handover frameworks [11][12], and have been applied to enhance other scenarios such as multimedia architectures [13]. Some approaches, such as [14] applied 802.21 events to information broker entities, able to fuse this heterogeneous link information with service and user parameters, further enhancing and optimizing handover decisions. However, none of these approaches considers the application of MIH mechanisms to abstract sensor technologies, nor the means to control and optimize how the generated sensor information is conveyed towards consumers in a flexible and efficient way. As such, it becomes necessary to have a structure that facilitates and disseminates sensor information from different kinds of sensing technologies, in such a way that can be transported through the wireless sensor network and into the access and core networks where consumers of this information might reside. Our proposed framework builds on the work started in [15], which provides a media independent way for controlling and obtaining information from sensors of different manufacturers and characteristics, while enhancing that design through its integration into a flexible gateway-based sensor information dissemination platform.

III. Media Independent Sensor Framework

In order to provide a media independent functionality towards sensors, we propose to extend the 802.21 abstraction services to encompass sensor technologies. Moreover, we take advantage of intrinsic 802.21 mechanisms and enhance and allow dynamic configuration towards the access of sensor information. We further enhance this design with the provision of throughput efficient mechanisms that enhance sensor information dissemination in large scope ambient intelligence scenarios.

A. Generic Sensor Service Access Point

As detailed in [10], 802.21 defines a cross-layer entity, the Media Independent Handover Function (MIHF), able to abstract the different link layer technologies to higher-layer entities (MIH-Users), facilitating information gathering and control of the links. The MIHF provides a set of services, enabling the collection of link events, issuing link commands and obtaining general network information. MIH-Users are able to use the MIHF services through a media-independent Service Access Point (SAP) interface, the MIH_SAP. The MIHF is then able to map the media-independent primitives into media-specific ones by interfacing with technology dependent SAPs, called the LINK_SAPs. LINK_SAPs for different IEEE and 3GPP technologies exist.

In our framework we enhance the 802.21 architecture by adding a new Generic Sensor SAP (Figure 1), extending the media-independent services to interface with different sensor technologies and adding an extensible set of sensor-related primitives.

This interfacing allows for information collection and control over different sensor families through the implementation of simple 802.21 translation procedures, as well as conveying information into MIH-Users in a media-independent way. Moreover, 802.21 allows MIHF services to be accessible remotely, via a MIH_NET_SAP. This SAP encapsulates the 802.21 information using the MIH Protocol (defined in [10]), which is able to be sent in a number of L2 or L3 underlying transport technologies.

Our framework features a flexible design for sensors whose capabilities (both in terms of processing and memory) are not able to encompass a full MIHF. The developed Generic Sensor SAP is able to be decoupled from the MIHF, remotely communicating using either a L2 or L3 protocol. In this way, sensors only require the existence of a MIHF-enabled gateway, providing the MIHF functionalities on their behalf. For sensor devices with even more stringent capabilities, which are not able to incorporate the Generic Sensor SAP at all, our framework enables the gateway to act as an intermediate point for the information and control interfaces provided by those sensor technologies. All possible scenarios are depicted in Figure 2.

B. 802.21 Extensions for Sensor Information Management

By developing our framework as an extension to 802.21, we are able to take advantage of intrinsic management features that provide an enriched and flexible way of disseminating sensor information. Concretely, the services provided by the Generic Sensor SAP can be conveyed to any MIH-User that registers for receiving events and issuing commands. This enables sensing information to be forwarded to multiple entities simultaneously, with each one able to use such information for different purposes.

Events can be sent normally according to sensors specification, but the MIHF allows MIH-Users to define thresholds (e.g., only report temperature after it has reached a certain value) or period (e.g., send luminance events every hour), placing the control of information freshness directly at the hands of the consumers. Our framework thus considers an event-based approach for the dissemination of sensing information and, as such, we do not focus on shared-databases. However, our framework is flexible enough to consider databases as the final consumers of events received from sensors, through simple adaptation of these procedures.

The Media Independent Information Service (MIIS) provides a specialized MIH-User, which acts as a repository for Information Elements (IEs), able to provide network topology and information. Even though this repository is mostly static in nature, we have developed novel IEs that can be queried by MIH-Users in order to determine sensor neighbor maps, highlighting their sensing and context capabilities. In addition, 802.21 provides discovery of MIHF-enabled entities, and their capabilities, which provide a dynamic mechanism for discovering sensor nodes and gateways. Each MIHF has its own identifier, which is used for remote information dissemination. By employing identifiers in our Generic Sensor SAP, we are able to address specific sensors, sets of sensors managed by a gateway, or even clusters of gateways connected by different access technologies to the Internet, for region-wide sensor information dissemination.

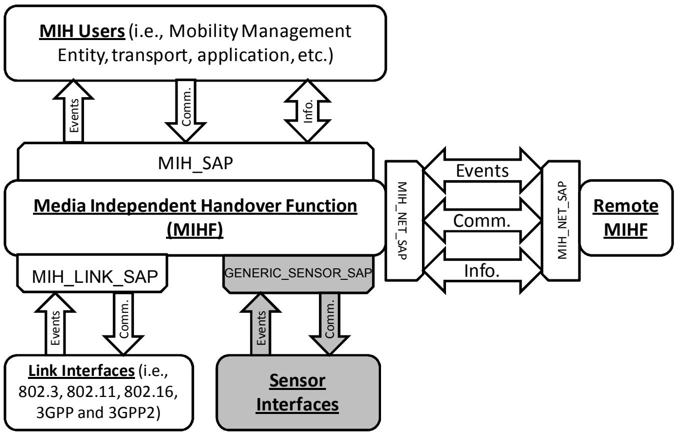

Figure 1 - Extensions to 802.21: The Generic Sensor SAP

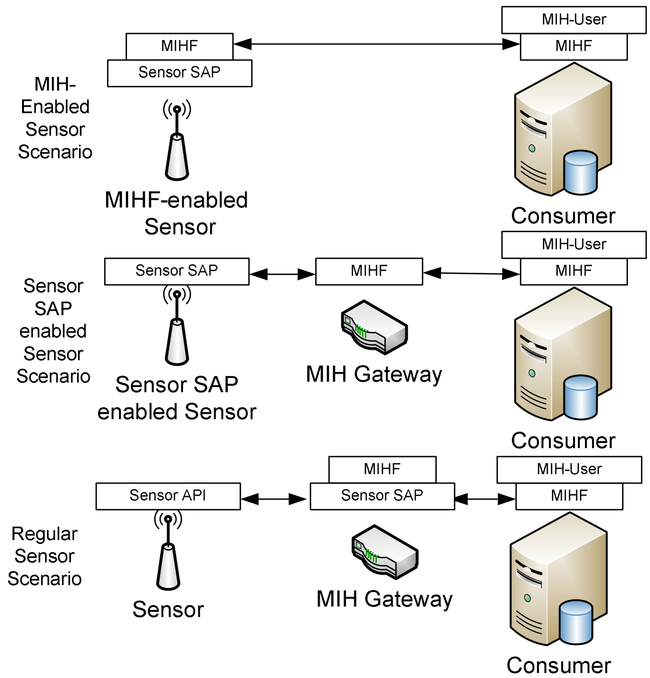

Figure 2 - Sensor Interfacing Scenarios

Also, since 802.21 has been developed considering mobility scenarios (and has also been extended to cover other areas), we can further extend them with the context information provided by sensors enabling fully integrated smart environments.

C. Frame aggregation and compression in large scale scenarios

In order to support these large-scale scenarios with clusters of gateways sending huge amounts of sensing information, we have developed information pre-processing mechanisms into our framework. As such, it is possible to take advantage of the gateways higher processing capabilities (when compared to sensor nodes) and optimize the dissemination of sensing information towards the consumers.

1) Gateway collection and aggregation of sensor events

In large-scale scenarios, huge numbers of sensors sending isolate events (each with its own event message and header) can generate large amounts of overhead. We have taken advantage of the gateway deployment possibilities in our framework, and developed an aggregation mechanism. With this, we allow sensor devices to send messages that are concentrated in a single large frame, which is forwarded to consumers. This approach prevents the overburden of the network path towards consumers and reduces the impact of constant event messaging in high sensitivity data streams.

Moreover, several different models can be applied to allow the gateway to provide information as a broker, supporting scenarios where information from multiple sensors can be fused together to present context information for a geographical area. In Section IV we explore possible models for event dissemination where aggregation is used.

2) Generic Sensor Services Compression

Event reporting messages are typically small, reaching sizes of 40 bytes (in our framework) for reporting three phenomena. However, large-scale scenarios featuring aggregated sensor events can generate very large messages, which can impact the network path between the gateway and the consumer, particularly if the gateway is wireless. In order to optimize bandwidth consumption, as well as battery usage from using the wireless interface, we have developed a dictionary-based algorithm.

When the gateway obtains the sensor events (and aggregates them in a single message, when aggregation is active) the compression method searches the data for the Most Used Bit (MUB) sequence. When it is found, the algorithm identifies all the positions in which it repeats itself creating an index of positions and then eliminates those repetitions. In order to maintain the integration ability of our framework with already-existing 802.21 architectures, MIH Protocol message parameters need to be encoded in TLV format. As such, the *MUB*, *Index* and *Compressed* where serialized into a newly defined 802.21 datatype TLV, as shown in Figure 3.

Converting the compression data into a TLV parameter broadens the usage of this parameter to any IEEE802.21 compliant entity. In this way, compression and decompression can be performed on sensor nodes, gateways, mobile terminals or other type of entity, may it be on a Sensor SAP, MIHF or MIH User.

IV. Performance Evaluation

In this section we intend to show the benefits of using our framework by submitting it to a theoretical scenario, where a gateway featuring our enhanced sensor-enabled 802.21, is able to receive media-independent sensing information from sensors of different kinds, and disseminate it according to different event retrieval requirements from information consumers. We further consider the energy consumption and performance obtained by compressing aggregated events. Tests in an actual deployment are part of our future work.

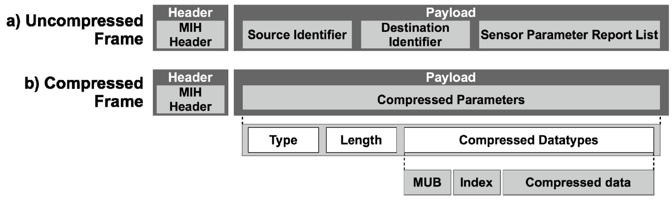

Figure 3 - Uncompressed and Compressed Frames

Figure 4 - Traffic Intersection Scenario

For our scenario, we have considered a traffic intersection as depicted in Figure 4. Three distinct kinds of sensors are monitoring the area, for a time period between 8h00 and 20h00: the first measures ultrasounds (counting the number of vehicles passing through the intersection), the second measures CO levels for assessing pollution caused by heavy traffic and the third measures luminosity, in order to control the semaphores' signal intensity according to the environmental luminosity.

For this scenario we have defined a chain of events with a variable number of cars, considering up to 400 cars per hour during peak hours (from 9h00 to 11h00 and from 18h00 to 19h00), with a minor peak of 250 vehicles (from 13h and 15h) and a minimum of 100 cars per hour. We considered the traffic peak hours as impacting directly the air pollutants sensors, providing CO levels ranging from 6 ppm and 9 ppm during these hours. Also, the luminosity sensor provides a maximum luminosity on 150 lux between 12h and 13h, a minimum of 60 lux at 20h.

A. Information Dissemination Models

We have compared the performance of our framework when different models for requesting events are used by sensor information consumers. We defined three types of event dissemination used in sensor networks: 1) Sampled Rate, 2) Threshold Defined and 3) Selective Periodic, explained in the following sections. Each model was compared with the gateway relaying independent events (e.g., without aggregation where each event occupied 30bytes) against using aggregation (where two or three events are aggregated, composing messages of 35 and 40 bytes respectively). For each model we analyze the total amount of bytes received from the three sensors, per hour period.

1) Sampled Rate Model

In this model, events are generated at the sensor sample rate: ultrasound rate is 250ms, air pollutants rate is 30s and luminosity sensor is 10s. Results present flat values, with the sensors constantly sensing events, the generated information per hour reaches 446K bytes without aggregation and 434K bytes with aggregation. Independently of the peak hours, the gateway keeps forwarding the sensing information at the rate it is generated by the sensors. Aggregation provides an overall byte transfer reduction of 2.7%.

2) Threshold Defined Model

In this model, consumers set a threshold for the three sensors at the gateway, which only forwards events when the respective defined values are crossed. Average values are used to avoid unnecessary resending of values. The used threshold configurations for the three sensors were: a car has passed the intersection, the CO levels rise above 8.5 ppm and the luminosity rises above 125 lux.

Results in Figure 5 show that threshold configuration reduces the amount of bytes generated, with and without aggregation. In average, per hour, 8K bytes non aggregated and 7K bytes aggregated are generated. The highest peak occurs at 19h00 with 22k and 14K for non aggregated and aggregated messages respectively, which are quite below when compared with the first model. When compared to the Sampled Rate Model, the Threshold Defined model sees its efficiency increased during peak time when sensor traffic is significantly increased. It is also during peak times that the usage of aggregation reduces the amount of byte transfer.

3) Selective Periodic Update Model

In this model MIH-Users set an event refreshing interval at the gateway, which only sends events when changes occur. In this case, the gateway can send, for example, only two events, if the value of the third sensor was deemed as unchanged.

Results in Figure 6 show that this model further reduces the amount of bytes generated from the previous models, even though aggregation only provides marginal byte savings.

B. Compression Efficiency

The results in the previous section show that aggregation only presents improvements when the amount of aggregated sensing events is substantial. Large amounts of sensing events can be obtained by scenarios featuring not one, but several (or even clusters) gateways connected to large sets of sensors. These scenarios, with an example depicted in Figure 7, enable the dissemination of sensing information pertaining to whole regions, providing context information over the Internet to consumers and enable highly complex smart environment scenarios. We argue that the amount of data generated in such conditions will impact the network: even though the path from the sensor to the gateway encompasses only sensing-related messages, the path from the gateway to the consumers is shared with other kinds of traffic. As such, we employ our compression mechanism to deal with the increase of information.

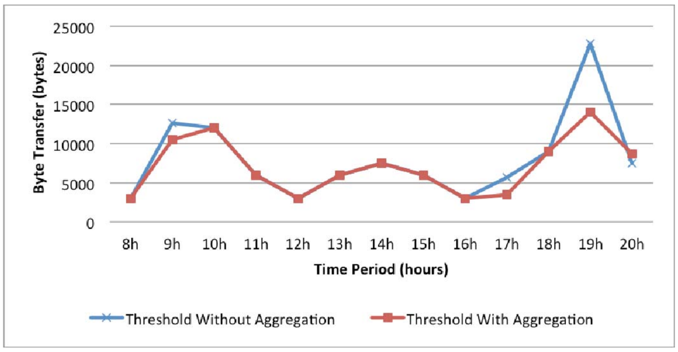

Figure 5 - Byte Transfer for Threshold Configuration

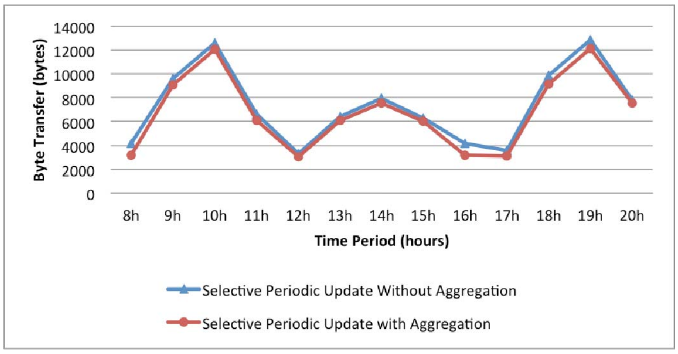

Figure 6 - Byte Transfer for Selective Periodic Update

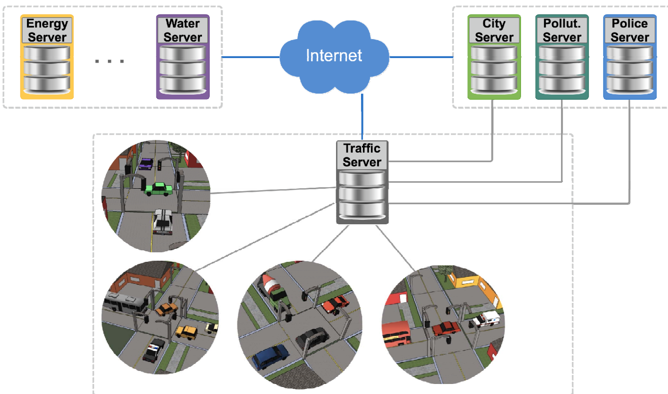

Figure 7 - Extended Scenario

To obtain compression performance figures, we developed a small scale testbed, implementing a gateway using a laptop running Linux Ubuntu 10.10 with a DUO T5450 Processor and 2GB RAM. We implemented our sensor extensions over ODTONE [16], aggregating 14 Sun SPOT sensor nodes to the gateway, generating events on temperature, luminance and accelerometer. Measurements were taken at the gateway node.

1) Compression performance

We measured the compression method performance, which is described in Table 1. This study shows that the compression method is more efficient for messages with higher size.

TABLE I. COMPRESSION PERFORMANCE

Number of Aggregated Events	Uncompressed Size	Compressed Size	Ratio
5	50	45	0.1
10	75	56	0.25
15	100	71	0.29
30	176	109	0.38
50	276	137	0.50

In order to evaluate the compression time, we tested an aggregated message with 256 bytes and measured how much time it would consume to generate our 802.21 sensor extended events, receive them at the gateway, aggregate them in a single message, compress and send it. 1000 message measurements were done, taking a mean time, for the entire procedure, of 32.3ms.

2) Compression Energy Consumption

Energy consumption is a critical parameter in wireless sensor networks. Considering the case where the gateway itself can be a battery-operated node, we compare the energy consumption placed by our compression algorithm when events where disseminated in non-aggregated and aggregated form. In the first, bursts of ten individual messages were sent in loops 5s apart for 10 minutes. In the second, a single message contained the ten events. For each form, we took 20 samples of the gateway power consumption using gnome-power-statistics, showing that a mean value of 21.42W and 21.03W were consumed by the first and second form, respectively. In this way, the power that can be consumed by performing the compression is mitigated by the gains of using less power to send less information, particularly over the wireless medium, as is substantiated by [17].

V. CONCLUSION

In this paper, we propose a sensor information dissemination framework, which leveraged 802.21, a media independent architecture, to contemplate sensor devices. We have further enhanced that design by introducing a series of mechanisms that facilitate the collection of sensor information, using gateways. Furthermore, we have presented and analyzed the performance, of optimization schemes to disseminate information gathered by the gateway towards consumers. Results have provided insights on the usefulness of aggregation and compression mechanisms, as well as the support of different event dissemination schemes.

Our future work will focus on the evolution of our live testbed, aiming to adapt our framework to different, and increasingly demanding, application scenarios.

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