# An Efficient Communication Control Approach for Next Generation Wireless Sensor Networks

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***Abstract.*** *Recent advances in wireless sensor systems allow the deployment and the access of a large diversity of sensor-based applications, such as real-time monitoring and controlling. In this heterogeneous environment, the efficient control of the battery consumption and of the communication overhead is essential. This paper proposes and evaluates an architecture to minimize signaling overhead and battery consumption, while keeping the end-to-end IPv6 connectivity in Wireless Sensor Networks (WSN). The evaluation is done through simulation and prototype experiments to analyze its impact regarding bandwidth and battery consumption.*

## 1. Introduction

Wireless sensor and actuator networks are now present in industries, houses, cities, vehicles and wild/non-urban areas. These networks are conducting to the emergence of a new generation of fine-granular measuring/controlling applications, context aware systems and smart spaces. A typical Wireless Sensor Network (WSN) is composed of numerous tiny, low cost, battery powered devices, which are expected to work unattended. This sensor nodes have as much computational power, storage and memory as early 90's personal computers and can perform sensory activity and data transmission, running a dedicated operating system [Hill et al. 2000].

Today's most common specification for wireless transmission, the IEEE 802.15.4, provides nominal data rates of 20, 40 and 250 kbps operating at 868MHz, 915MHz and 2.4GHz respectively. This standard allows star, clustered tree and ad-hoc topologies [IEEE 2003] and can be found in diverse applications, such as home and industrial automation, health care, precise agriculture, urban sensing and wildlife monitoring. In addition, with the cost per sensor node getting lower and the platforms becoming easier to program and operate, these and other applications would be even more common. The proliferation and simplification will also allow end-users to make available their sensing data to the Internet and any authorized user will be able to find them through any searching mechanism, such as Google [Estrin et al. 1999].

However, CPU, memory and bandwidth restrictions have imposed the adoption of application specific protocols to run on the sensor nodes and the worldwide connectivity can be reached only through proprietary proxies or web servers solutions [Estrin et al. 1999] and [Zúñiga and Krishnamachari 2003]. This approach can fit the communication needs of specific applications with the most efficient protocol stack, but at a cost of demanding more development effort for each different case and increasing complexity to interconnect with other networks.

Whereas tailored proprietary solutions for wireless sensor network communication tend to be more economical in terms of energy consumption, memory usage and processing power, an IP architecture provides seamless world wide connectivity and demands less development effort. In addition, IP internetworking technology has an open specification, as well as tools for diagnostics and management [Montenegro et al. 2007]. In order to build an IPv6 stack suitable for constrained devices, the 6LoWPAN Internet Engineering Task Force Working Group (6LoWPAN IETF-WG) has been solving problems such as IP communication overhead, packet fragmentation and reassembling, network auto-configuration and mobility [Montenegro et al. 2007]. The result is the IPv6 for low power personal area networks (6LoWPAN) standard.

The 6LoWPAN scheme significantly reduces the IPv6 communication overhead through cross-layering suppressing mechanisms and a pay-for-what-you-use approach, highlighting IPv6 as a promising technology to enable a new generation of WSNs [Culler and Hui 2007]. However, the most energy efficient manner to deploy IPv6 enabled WSN offers only link-local connectivity. In this way, the 6LoWPAN cross-layering mechanisms can avoid the layer 3 addressing, since the link-local IPv6 addresses are formed from layer 2 addresses. This characteristic leads us to the proposition of the 6GLAD architecture [Zimmermann et al. 2008] to exploit the 6LoWPAN cross-layering optimizations without losing the global network connectivity.

However, a good understand of the 6GLAD savings in bandwidth utilization and, as a consequence, energy saving is still missing. This paper extends our previous work with an analysis of the network traffic, the energy consumption and signaling overhead in Internet connected wireless sensor networks. In order to evaluate the benefits of the proposed solution, prototype and simulation experiments are performed to measure the impact of 6GLAD regarding signaling overhead and energy consumption.

The remainder of this paper is organized as follows. Section 2 covers the related work. Section 3 gives an overview of the 6GLAD architecture. Section 4 covers the evaluation methods, the equipments, software, tools and respective results. The concluding remarks and the future work are covered in Section 5.

## 2. Related Work

In [Kushalnagar et al. 2007] a characterization of low power personal area networks (LoWPAN) is given and the problems related to the use of IPv6 over these kinds of networks are covered. In addition, an overview of the 6LoWPAN protocol stack is presented and the goals and focus of the IETF-WG are outlined. The proposed research leads to the publication of the IETF standard for IPv6 over IEEE 802.15.4 networks, published in [Montenegro et al. 2007], which defines the dispatch values, header formats, encoding techniques and compressing mechanisms for 6LoWPAN.

Furthermore, the research described in [Mulligan 2007] presents a comparison, in terms of code size, total header overhead, maximum number of nodes supported, types of mesh routing algorithms supported and Internet connectivity, between 6LoWPAN, Zigbee and Zensys protocol stacks. This study shows that 6LoWPAN, more than allowing seamless connectivity between constrained devices and the Internet, is a competitive solution.

The benefits of the 6LoWPAN scheme is also introduced in [Culler and Hui 2007] and in [Mulligan 2007]. The authors presented an overview of IEEE 802.15.4 and 6LoWPAN overhead analysis through a graphical comparison of energy costs to transmit and receive packets over a raw IEEE 802.15.4 link and after the 6LoWPAN headers added. In addition to the previous proposals, our previous work [Zimmermann et al. 2008] presented a detailed description about the communication overhead related to each 6LoWPAN header. Exhaustive scenarios are also used to analyze the total header size of each different topology. In addition, a new architecture is proposed to keep the worldwide connectivity while avoiding the costly scenarios.

The analysis of related work showed that none of the approaches performed experiments to verify the impact of their proposals regarding energy consumption and signaling overhead. To overcome the above issues, this paper introduces the 6GLAD solution together with an exhaustive study regarding signaling overhead impact in different scenarios. In addition, prototype experiments are performed to analyze the efficiency of our proposal regarding bandwidth and battery consumption in real environments. In the simulation experiments, 6GLAD is analyzed together with 6LoWPAN and pure IPv6 approaches.

## 3. The 6GLAD Architecture

6GLAD is the acronym for IPv6 Global to Link-layer Address Translation and its objective is to exploit the 6LoWPAN cross-layering mechanisms to diminish the IPv6 overhead. In fact, 80% of the basic IPv6 header (32 bytes from 40 bytes) is spent in source and destination address fields and this is the point where 6LoWPAN adaptation layer plays its major role. When a packet is transmitted in a 6LoWPAN WSN, instead of carry all the layer 3 fields, it goes only with the instructions to rebuild them. If two hosts are communicating whit link-local addresses, the hole IPv6 source and destination addresses can be reconstructed from layer 2, i.e. FE:80::(MAC Address).

However, in global communication scenarios there is little or nothing to reconstruct at layer 3 from layer 2. Therefore, In order to extend the gains of 6LoWPAN also for global communication scenarios, the 6GLAD agent performs Network Address Translation (NAT) operations, namely NAT and reverse NAT (twice-NAT). These operations provide global connectivity while the 6LoWPAN adaptation layer can keep the IPv6 overhead at the lowest level. The details of this architecture can be seen in [Zimmermann et al. 2008]. The 6GLAD approach is transparent to other network agents, nodes, services and end-users, since it avoids changes in the global system. It can be placed with the 6LoWPAN router as in the scenario of Figure 1.

Inside the WSN, packets carry only link-local addresses in both source and destination fields, which are mapped to global addresses at the 6GLAD gateway. The end-to-end connectivity between every sensor node and any other device in the Internet is maintained through the double mapping tables, where the sensor node´s link-local addresses are mapped to their respective global address and the Internet hosts which are in communication with a WSN node have their global addresses mapped to a reserved set of

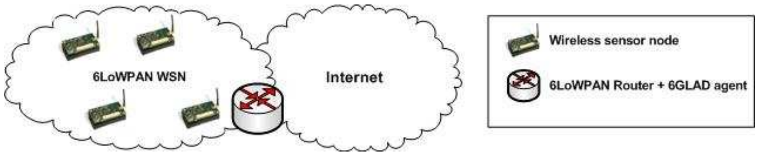


**Figure 1. The 6GLAD Agent**

link-local addresses.

## 4. Performance Evaluation

Despite the gains in terms of header compressing, a performance evaluation study was necessary to evaluate how much saving the 6GLAD proposal can offer to real scenarios. The objective of the simulation experiments was the analysis of the bandwidth consumption in bigger WSN scenarios and to confirm, in absolute terms, the energy efficiency of 6GLAD and the battery consumption, a prototype experiment was done in a MicaZ mote testbed.

### 4.1. Test-bed Experiments

The evaluation performed in the testbed presented in Figure 2 was based on a PING-PONG application over UDP. The application was analysed in three scenarios as follows: 6LoWPAN with link-local addresses (named 6GLAD), 6LoWPAN with global addresses (named 6LoWPAN) and IPv6 with all fields carried inline (named IPv6). The three scenarios allow end-to-end IPv6 connectivity between sensors and Internet hosts.

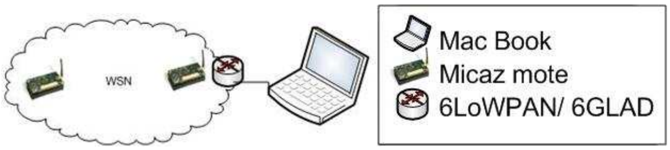


**Figure 2. The Testbed**

For each scenario, a sensor node is equipped with a specific nesC application programmed to reply each PONG with a PING message, reporting the sensor node battery power. The sink node is connected to a laptop running a Java application configured to send a PONG message at each second, wait for the PING replies and store the battery reports received from the sensor node.

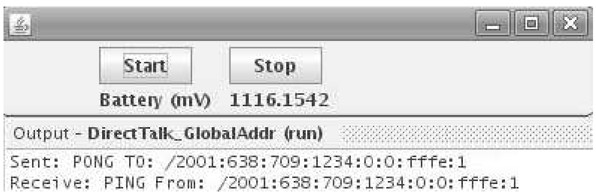


**Figure 3. The Battery Measurement Tool Interface**

The objective was to analyze the impact on the battery consumption. In order to get the values, it was developed an application that measures the energy level, in milivolts, and sends the message to the sink node. The Figure 3 presents the application interface during the measurements, in which it can be verified the last battery value received, the PING Sent and the PONG Received. To support the evaluation, two sniffers agents were used. The first agent, that was used for Layer 3, is known as wireshark [Combs 2008] and is based on the tcpdump [TCPdump-Team 2007]. The second agent was used to analyse the Layer 2, it is known as serial tun and it is included in the 6LoWPAN implementation in the TinyOS.

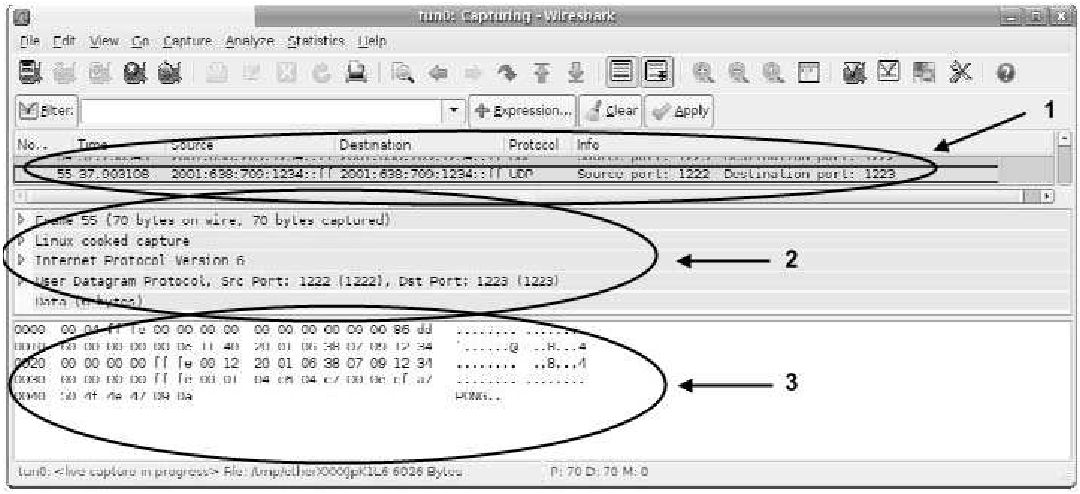


**Figure 4. The Wireshark Interface**

The Wireshark was very useful for the evaluation and the analyses of the packet reconstitution by 6LoWPAN at layer 3. The Figure 4 presents its interface capturing a PONG message with its respective fields. *Area 1* shows the general information about the packet (Source Address, Destination Address, Transport Protocol = UDP, Source Port and Destination Port), *area 2* shows the detailed information about the packet (Size, Operating System, Version, etc) and *area 3* shows the payload.

The serial tun is an application to allow the communication through the serial port, making it work as an Ethernet interface. It also plays the role of a sniffer, showing the received packets and its size. The serial tun interface capturing a packet during the performed evaluation can be seen in Figure 5. *Area 1* shows that the packet suffered IPv6 compressing, *area 2* shows the length after compression is 57 bytes, *area 3* shows the source IPv6 address and *area 4* shows the destination IPv6 address. After layer 3 reconstitution, as present in Figure 4, the packet size will be 70 bytes.

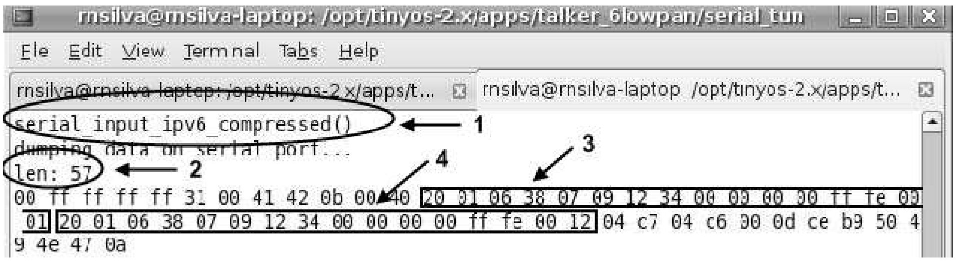


**Figure 5. The Serial tun Interface**

The sniffers were useful to learn the applications behavior and replicate it in the simulation environment. The Java application to monitor the battery exhaustion reported values that are summarized in Table 1. The Base value is the amount, in milivolts, spent to send the battery report each 5 seconds during 30 minutes.

**Table 1. Tension reduction on the batteries after 30 minutes**

| Scenario | Base | 6GLAD | 6LoWPAN | IPv6 |
|---|---|---|---|---|
| mV reduced | 1,99 | 7,23 | 11,72 | 17,97 |

The measurements reveal that, compared to the pure 6LoWPAN scenarios, the 6GLAD approach improve 38% the sensor node overall energy efficiency. If we discount the 1.99 milivolts spent in just beeing alive and report the battery values at each 5 seconds of both scenarios, 6GLAD and 6LoWPAN, the 6GLAD scenario is 46% more efficient.

### 4.2. Simulation

In order to evaluate the impact of communication overhead in bigger networks, 6GLAD is simulated using the Network Simulator 2 (NS2). Eight star-based topologies were generated by GenSeN topology generator [Camilo et al. 2007]. The GenSeN generates WSN topologies based on studies of real WSN deployments. Since signaling overhead is the focus of this paper, all sensor nodes are configured with the same energy and transmitting range. The first topology has one 6GLAD agent and two sensor nodes as it was evaluated in the testbed experiment. The number of sensor nodes in the remainder topologies increases following an exponential approach (4, 8, 16, 32, 64, 128 and 256 nodes).

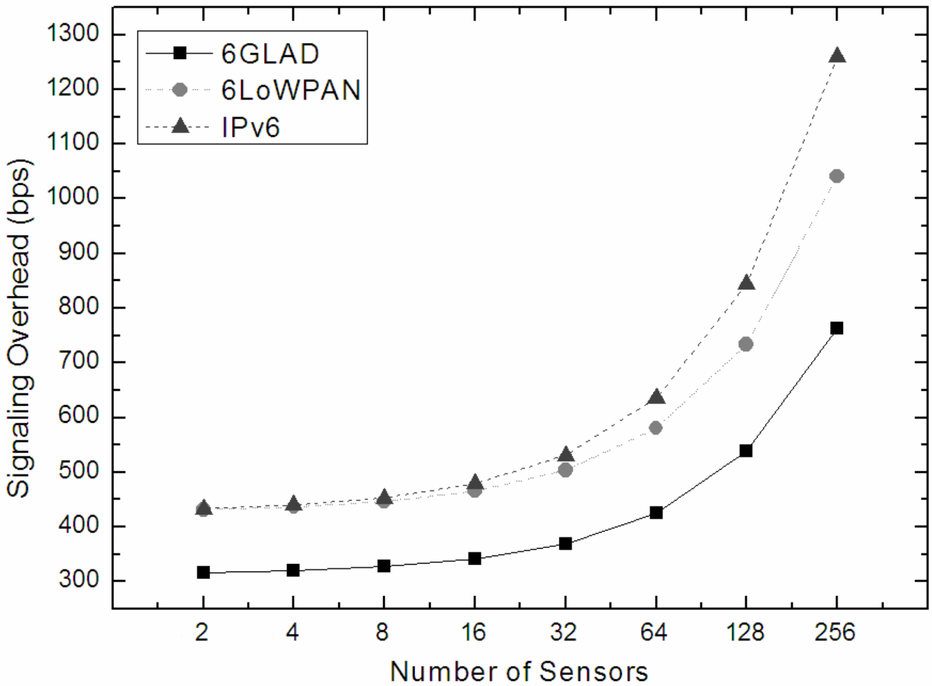


**Figure 6. Bandwidth consumption for each scenario**

In addition, an application with the same packet size and traffic partner as used in the test-bed is implemented. To verify the 6GLAD behavior in different scenarios, an NS2 agent was developed to send and receive information from the sensor nodes, and to perform connectivity and address translation operations. Moreover, in order to avoid request/response message synchronization and overload in the 6GLAD agent, the timer used to send a request message for each sensor node varies from 0s to 1s (random timer). Figure 6 illustrates the amount of signaling overhead with 6LoWPAN behind a 6GLAD gateway, standard 6LoWPAN and standard IPv6 during 30 minutes of simulation for all scenarios.

The results reveal the efficiency of 6GLAD in reducing the signalling overhead in all scenarios. Compared with the pure 6LoWPAN scheme, 6GLAD minimizes the signalling overhead in approximately 27% in all scenarios. When 6GLAD is compared with a pure IPv6 scenario, it reduces the amount of signalling overhead in 27% when the scenario is composed of two sensors and increases up to 40% when the scenario is equipped with 256 sensors.

## 5. Conclusion and Future Work

The 6GLAD proposal provides an efficient communication control solution for next generation sensor networks. The proposed scheme operates in a transparent mode and does not require changes in the global communication system. Prototype experiments show the energy efficiency of the proposed solution when it is compared with pure IPv6 and 6LoWPAN experiments. The testbed measurements reveal the 6GLAD architecture saves 46% more energy than a pure 6LoWPAN scheme. In addition, simulation results present the benefits of 6GLAD regarding signaling overhead compared with IPv6 and 6LoWPAN solutions. Eight simulation scenarios (with different number of sensors) were analyzed and reveal that 6GLAD minimizes the signaling overhead of the link in 27% and 40% compared with IPv6 and 6LoWPAN schemes, respectively. As future work, the 6GLAD agent implementation for NS2 will be extended to allow flexibility to simulate 6GLAD in large scale networks. Moreover, the standardization of 6GLAD in the 6LoWPAN working group will be proposed.

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