Adaptive Multimedia Transmission in Wireless Sensor Networks

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***Abstract* — Multimedia transmissions over wireless sensor networks may provide valuable information of the monitored field, enhancing monitoring and control applications. However, multimedia streaming can considerably shorten the expected lifetime of battery-operated sensor networks due to the large amount of information to be transmitted from multimedia-enabled source nodes. On the other hand, multimedia data may have different relevancies for the application, depending on the performed monitoring tasks and the application requirements. In such context, we propose an adaptive context-aware energy-efficient multimedia transmission approach, where intermediate nodes may consider its current residual energy level and preconfigured energy thresholds to decide if multimedia packets must be relayed to the next hop or silently discarded. Doing so, energy is saved and the expected network lifetime is enlarged, with controlled impact on the overall monitoring quality.**

***Keywords* — Wireless sensor networks; Energy-efficient adaptive transmission; Multimedia streaming; Packet relaying.**

I. INTRODUCTION

Wireless sensor networks (WSNs) have been employed in a large series of monitoring and control applications, changing the way information is harvest and retrieved from the monitored field [1][2]. Besides scalar information such as humidity, pressure, temperature and luminosity, sensor nodes may be endowed with multimedia sensing units, enriching monitoring applications with audio, still images and video streams [3][4]. The resulting Wireless Multimedia Sensor Networks (WMSNs) present new possibilities for monitoring and control applications, but also bring new challenging issues that need to be addressed.

In typical wireless sensor networks, nodes are constrained in energy, processing and memory resources due to the effort to reduce its cost, in order to allow its massive deployment [5]. Energy constraints bound the wireless communication range and impose controlled use of transmission and processing functions. Furthermore, processing and memory constraints can impact the use of buffering techniques by communication protocols, as long as the execution of optimization codes. In addition to the fact that wireless sensor networks may be deployed in regions with lack of infrastructure, or even in hazard or hard access areas, sensors nodes are expected to be autonomous and battery-operated. It is also expected that monitored data will flow upstream through ad hoc multihop communication links [6].

Transmitting multimedia data in WSNs is indeed a challenging task, either due to the large amount of data to be transmitted or due to the real-time nature of some multimedia monitoring applications. In fact, it is expectable that much more energy will be consumed in the transmission of packets over wireless links than in storing and processing operations [7]. In other words, the network lifetime directly depends on the energy consumption rate, and multimedia streaming is expected to consume much more energy than transmission of scalar data [4].

Wireless multimedia sensor networks may be employed to retrieve any combination of audio, still images, video streams and scalar data. Specialized source nodes may be deployed to retrieve a particular type of data or multipurpose sensor nodes equipped with a low-power camera and a microphone may be employed, resulting in different configurations of homogeneous or heterogeneous networks. Whatever the case, packets carrying pieces of audio, image, video or scalar data from different source nodes may be crossing the network toward the sink, whether sources' transmissions are continuous or triggered-based. As packet relaying consumes most energy and transmission paths may be disabled due to energy depletion of intermediate nodes, the total amount of information transmitted over the network should be minimized as much as possible, potentially prolonging the network lifetime. Such energy depletion is more harming in braided-paths [8], where a single intermediate "hub" node may relay packets from more than one source. As these intermediate nodes belong to more than one path, they are expected to receive more combined upstream traffic than other intermediate nodes, thereby spending more energy in average.

Transmission of multimedia data presents different energy consumption patterns. Depending on the nature of the monitoring applications, they may also have different relevancies. For example, in wildlife observation, visual information might be more relevant than audio. On the other hand, audio streaming may be more desirable for an underwater whale monitoring system. Furthermore, multimedia data may be only retrieved to complement traditional scalar information. Whatever the case, we expect that each application defines a monitoring profile, indicating the relevance of different types of data, concerning multimedia and scalar data alike. As different levels of relevance may be identified, data packets may be prioritized according to their payloads.

We propose in this paper an adaptive multimedia transmission approach where each non-mobile intermediate node decides to relay multimedia data packets to the next hop according to its residual energy level and to the packets' priority. Each priority is associated to an energy threshold to be preconfigured in the desired intermediate nodes. As the energy level of intermediate nodes will decrease along the time, the overall amount of data to be relayed will also decrease, potentially saving energy and prolonging the network lifetime. We performed simulations over the proposed approach in order to highlight the expect energy saving over traditional relaying mechanisms.

The remainder of this paper is organized as follows. Section II presents some related works. Section III brings the statements and definitions of the proposed approach. Simulation results are presented in Section IV, followed by conclusions and references.

II. RELATED WORKS

Many works in recent years have been investigating multimedia streaming in wireless sensor networks [4]. Issues as energy consumption, real-time data delivery and error and congestion control have been major concerns [6] [9], leading research in this area. In such context, we are especially interested in research works that have influenced our investigation.

The work in [10] exploits multipath routing along with the relevance of multimedia data for efficient path selection. Authors define the MPMPS (Multi-Priority Multi-Path Selection) algorithm to find paths with lower end-to-end delay for multimedia streaming, considering a set of available node-disjoint paths [11]. As in [12], the source video stream (72 kbps) is split into an image stream (48 kbps) and an audio stream (24 kbps), giving to each resulting substream a particular priority according to the current monitoring being performed. The node-disjoint paths with lower delay are assigned to the higher priority substreams, leaving the remaining paths to the lower priority substreams. In a different way, the work presented in [13] proposes a transmission mechanism where each intermediate node decides to relay image packets to the next hop according to its residual energy and the packets' priority. Each transmitted packet has a priority level according to the relevance of Discrete Wavelet Transform (DWT) subbands. Doing so, the quality of images transmitted from any source node will be reduced but energy saving is achieved, specially benefiting communications over braided-paths. Similarly, we presented in [14] an energy-efficient packet relaying approach where intermediate nodes forward packets to the next hop toward the sink according to their residual energy level and predefined energy thresholds. However, in that work, packets' priorities are established based on the sensing relevancies of visual source nodes.

We indeed propose herein an energy-efficient packet relaying approach, but in a different way of [13] [14], the type of the retrieved data is considered when setting the packets' priorities, as in [10][12]. Basing the forwarding decision in the current monitoring tasks, we achieve an adaptive context-aware relaying approach, offering a new possibility for multimedia packet transmission over wireless sensor networks.

III. ADAPTIVE ENERGY-EFFICIENT MULTIMEDIA TRANSMISSION

After deployment, many nodes will be employed to compose a multihop ad hoc wireless communication infrastructure. Such intermediate nodes will relay data packets from source nodes toward the sink, employing some MAC and routing protocol. The actual energy consumption in each node due to the packet relaying operations depends on many factors, as the employed radio, the transmission power and the physical and MAC protocols. In this last case, duty-cycle MAC protocols are often used in wireless sensor networks to avoid idle listening, which play an import role in energy wasting [15]. Completing such complex scenario, synchronization messages may be transmitted among the nodes to optimize the sleeping time.

During the multihop communication, each packet may be acknowledged by a 1-hop ACK message. When a packet is successfully received and acknowledged by an intermediate node, it may decide to silently drop the incoming packet in order to save energy. Although the monitoring quality may be somehow negatively impacted when some packets do not reach the sink, such approach may turn the network active for a longer time.

We propose a threshold-based packet relaying mechanism where the current energy level of the relaying nodes (referred as e) indicates what type of data packets may flow over the network. As long as applications define a monitoring profile, each data packet will be dynamically assigned to a priority level according to the packet's payload. The type of the packets' payloads is identified employing a 2-bit Data Type (DT) field, which is expected to be inserted in every packet's header. Table I presents a typical configuration for the DT field of multimedia packets.

Depending on the intended level of differentiation of data packets, different values for DT can be used, being this field enlarged. For example, image snapshots, infrared and thermal images might represent different contents for the applications, requiring new values for DT.

TABLE I
Values for the DT.

Type of Data	DT
Scalar	0
Audio	1
Image	2
Video	3

Intermediate nodes that are implementing the proposed relaying approach will rely on the values of DT to assign a priority level to data packets. Each priority level will be directly mapped to an energy threshold, which will be considered when deciding if incoming packets must be forwarded to the next hop or silently dropped. Adopting energy thresholds create an adaptive behavior for the network, where the overall application quality decreases along the time but the network lifetime is enlarged.

Three different energy thresholds are defined: e_1, e_2 and e_3. When e is below one of the thresholds, only a subset of data packets must be relayed, while the remaining packets are silently dropped. While the DT of data packets depends exclusively on the packets' payloads, the monitoring profile will indicate what data contents are relevant for the application depending on the current energy level of intermediate nodes. Table II presents four different monitoring profiles, each one with a particular prioritization policy. However, users could create and employ any monitoring profile, just defining the type of data that must be relayed depending on the current energy level and thresholds. Note that for each monitoring policy, there is a type of data that will be always delivery to the sink, whatever is the current energy configuration of intermediate nodes.

TABLE II
Relaying strategy depending on the monitoring profile.

Energy level	Packets that must be relayed
Profile 1	
$e \geq e_1$	Scalar, audio, image and video
$e_2 \leq e < e_1$	Scalar, audio and image
$e_3 \leq e < e_2$	Scalar and audio
$e < e_3$	Scalar
Profile 2	
$e \geq e_1$	Audio, image, video and scalar
$e_2 \leq e < e_1$	Audio, image and video
$e_3 \leq e < e_2$	Audio and image
$e < e_3$	Audio
Profile 3	
$e \geq e_1$	Image, audio, video and scalar
$e_2 \leq e < e_1$	Image, audio and video
$e_3 \leq e < e_2$	Image and audio
$e < e_3$	Image
Profile 4	
$e \geq e_1$	Video, audio, image and scalar
$e_2 \leq e < e_1$	Video, audio and image
$e_3 \leq e < e_2$	Video and audio
$e < e_3$	Video

We consider that the initial energy level of the intermediate nodes is $e = 1$, and that they become inoperative when they run out of energy, $e = 0$. We can also state that $0 \leq e_3 \leq e_2 \leq e_1 \leq 1$. For e > e_1, all incoming packets will be forwarded to the next hop toward the sink. For the remaining possibilities of e and energy thresholds, packets will be relayed according to the considered monitoring profile. Considering that the application profile is already known, intermediate nodes should be preconfigured before deployment in the monitored field. However, a dynamical configuration mechanism might be employed to automatically configure the intermediate nodes, potentially adapting the network if the considered monitoring profile needs to be changed. As we are concerned with energy saving results when employing the proposed relaying approach, we assume that intermediate nodes are already configured when source nodes start transmission and that such configuration is steady.

Each intermediate node takes the decision of relaying or dropping packets based only on its residual energy, in an open-loop approach. Doing so, intermediate nodes do not need to know the energy status of neighbor nodes, reducing complexity and avoiding the transmission of feedback messages. For networks composed of braided-paths, the proposed relaying approach should be adopted by only hub nodes, which are more energy-critical. Therefore, employing the proposed optimization approach in only critical intermediate nodes turns open-loop processing a proper option.

As the monitoring quality will be directly associated with the monitoring profile, the proposed relaying approach is expected to have a reduced impact on the monitoring quality when compared with optimization algorithms based only on the relevancies of packets' payloads.

Based on several energy consumption models designed in the last few years [7] [9] [13], there is a basic notion that more packets to be transmitted (or received) consume more energy of the nodes, potentially impacting the network lifetime. In general words, more energy is expected to be consumed over the network when packets have to be relayed through more intermediate nodes. Thus, in theory, energy saving should be achieved when some packet relaying is avoided. However, energy consumption in wireless sensor networks depends mostly on the time that wireless radio is turned on, and thus idle listening and sleeping time have a major role when computing the expected energy consumption. Therefore, the proposed approach will be validated through realistic discrete event simulations, as presented in section IV.

IV. SIMULATION RESULTS

The proposed context-aware energy-efficient multimedia streaming approach can be employed to save energy in real-world wireless sensor networks, turning the network active during longer time periods. As different applications may have different monitoring profiles, the application quality is expected to be not severely harmed, since data that is most relevant for applications is always preserved. Thus, the performed simulations are concerned with the energy efficiency of the proposed approach over a traditional transmission mechanism, where all data packets are always relayed to the next hop whatever is the current energy level of intermediate nodes.

We conducted a series of simulations where different source nodes are deployed, retrieving different type of monitoring data. The simulations were performed employing the framework Castalia [16], which was adapted to incorporate packet relaying based on the relevance of packets' payloads. Castalia is a C++ discrete event simulator based on the OMNet++ platform.

Source nodes will transmit data packets according to their expected sensing functionality. We assume a specific configuration for each type of data, as described in Table III, although other configurations are also possible. For data packets sizing 125 bytes, with an effective payload area of 110 bytes, we expect that every scalar source node will transmit a single data packet (informing e.g. temperature, pressure or humidity) every second. Audio and video source nodes will continuously stream data packets, while image sources will transmit a single compressed still image per second. In fact, this continuous monitoring approach is highly energy-consuming for real-world wireless multimedia sensor networks, but it is valuable to present the expected energy saving when employing the proposed relaying mechanism. Note, however, that energy-efficient packet relaying based on the relevance of packets' payloads can also be achieved for triggered-based monitoring applications, since intermediate nodes will employ the same prioritization and relaying approach.

TABLE III
Codec and transmission rate for each data type.

Media	Codec	Rate
Scalar	Raw data	1 kbps
Audio	G.723.1 speech or noise	6.3 kbps
Image	JPEG 10:1 128 x 128 grayscale	13.1 kbps
Video	H.263 QCIF 15fps	48 kbps

We initially intended to assess the energy consumption of individual source nodes, for a very simple linear multihop wireless sensor network composed of four nodes (source, sink and two intermediate nodes). The assessment of the energy consumption pattern for the transmissions of a single source node is presented in Fig 1, where data packets have to be relayed through two ordinary intermediate nodes (without packet prioritization) to reach the sink. As each of the considered data types expressed in Table III imposes a particular transmission rate, we can note substantial variations in the average energy consumption of the network for the performed tests.

Scalar data is usually represented by few bytes, requiring transmission of few data packets along the time. On the other hand, even compressed video streaming may consume much more energy, significantly reducing the network lifetime. It is expectable that wireless multimedia sensor networks will employ most of camera-enabled source nodes for image monitoring, which is a less stringent approach for visual monitoring. However, video streaming can be desirable for many applications, fostering the adoption of optimizations approaches as the proposed energy-efficient packet relaying mechanism.

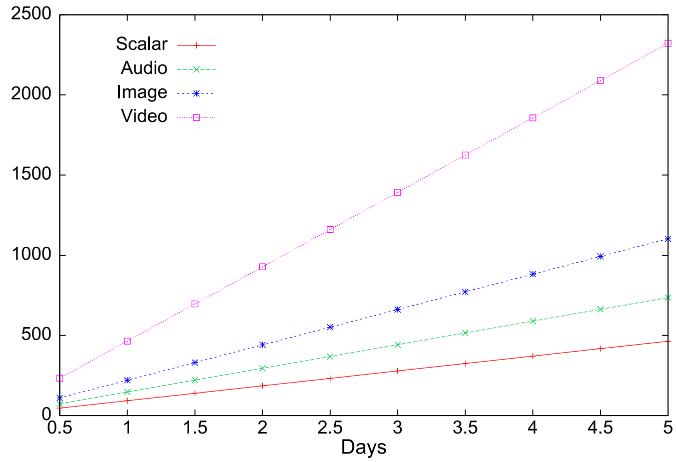

Fig 1. Average energy consumption (J) of the network.

In order to assess the performance of the proposed relaying mechanism, consider a typical heterogeneous communication scenario, as depicted in Fig 2. There are six source nodes transmitting different data contents to the sink, where each node is communicating using a duty-cycle MAC protocol [15]. The intermediate node n1 receive most data traffic and thus should relay data packets according to the packets' payloads in order to enlarge the expected network lifetime.

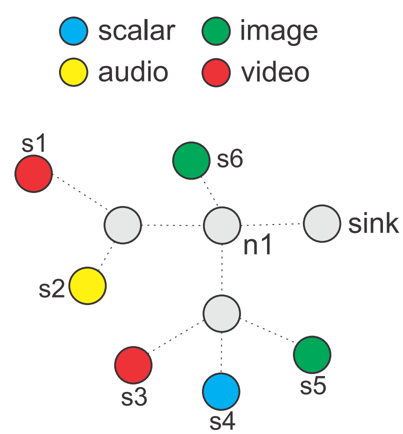

Fig 2. A heterogeneous communication scenario.

Assuming the maximum distance between neighbor nodes as 10 meters and that every node has a transmission power of -5dBm, we can assess the energy consumption of node n1 along the time. The four monitoring profiles described in Table II were considered, as well as a traditional relaying mechanism where every incoming packet is always relayed to the next hop. The initial energy level of the nodes was established in 28000J.

Fig 2 presents the energy consumption of node n1, assuming transmission of monitoring data during 5 days. We also consider $e_1 = 0.9$, $e_2 = 0.6$ and $e_3 = 0.3$.

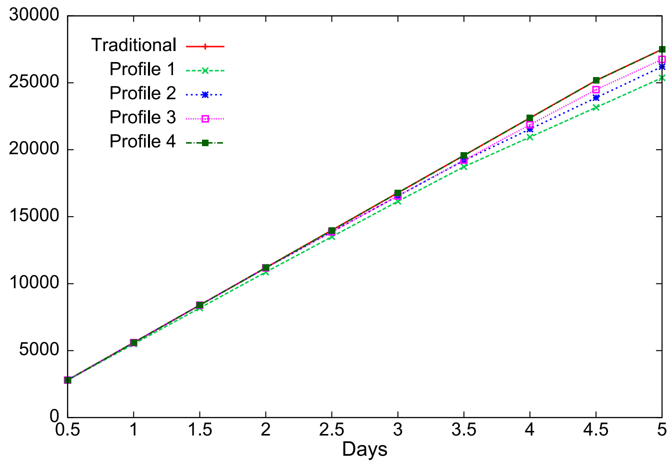

Fig 3. Energy consumption for the 1st configuration of energy thresholds.

As can be noted in Fig 3, Profile 4 and the traditional transmission approach consume almost the same energy. It is because video streams are the most significant data for the application with Profile 4, and video consumes most energy. On the other hand, transmission following Profile 1 consumes least energy since scalar data is prioritized over the other data types, and scalar data transmission consumes less energy.

The energy saving of the proposed context-aware relaying approach is highly dependent on the transmission configuration and the predefined energy thresholds. Fig 4 presents the energy consumption of node n1 for the thresholds $e_1 = 0.95$, $e_2 = 0.8$ and $e_3 = 0.65$.

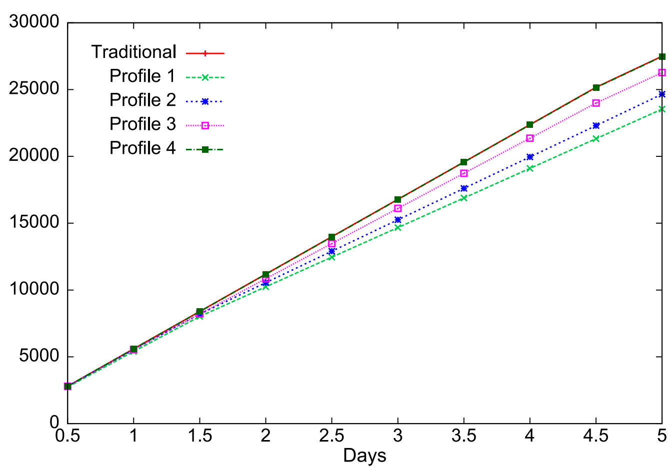

Fig 4. Energy consumption for the 2nd configuration of energy thresholds.

For a configuration of energy thresholds with higher values, packets will be silently dropped in intermediate nodes in early stages of the network lifetime. Doing so, energy saving will be achieved as less data packets will have to be relayed, potentially enlarging the network lifetime. Note that changing the energy thresholds only alter the total expected amount of energy saving, but do not impact the proportion of energy consumption of each monitoring profile.

In order to highlight the expected energy saving after 5 days of transmissions, we isolated the final energy consumption presenting this subset of results in the graphic of Fig 5. We also assumed the energy thresholds $e_1 = 0.95$, $e_2 = 0.8$ and $e_3 = 0.65$.

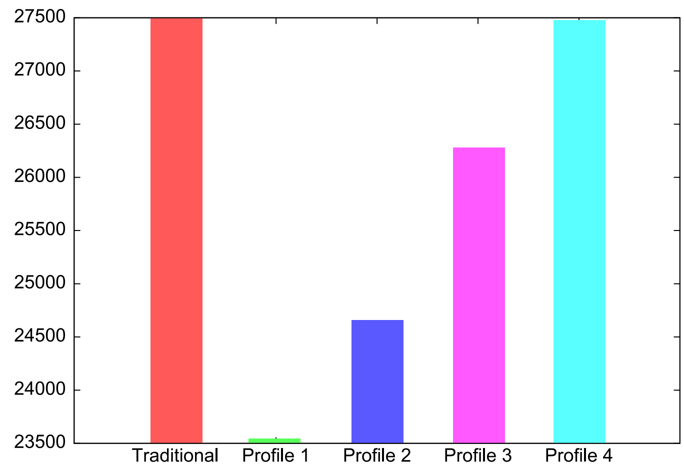

Fig 5. Energy consumption after 5 days of transmission.

Video streaming in wireless multimedia sensor networks is expected to consume most energy of the nodes. As an example of how stringent video streaming can be, we redefined the communications scenario on Fig 2 considering that three of the camera-enabled source nodes will transmit still images, instead of two. In other words, only one source node will stream video.

The energy consumption in node n1 was assessed again for 5 days of transmission, as depicted in Fig 6. We considered the same energy thresholds of the previous simulations, which were $e_1 = 0.95$, $e_2 = 0.8$ and $e_3 = 0.65$.

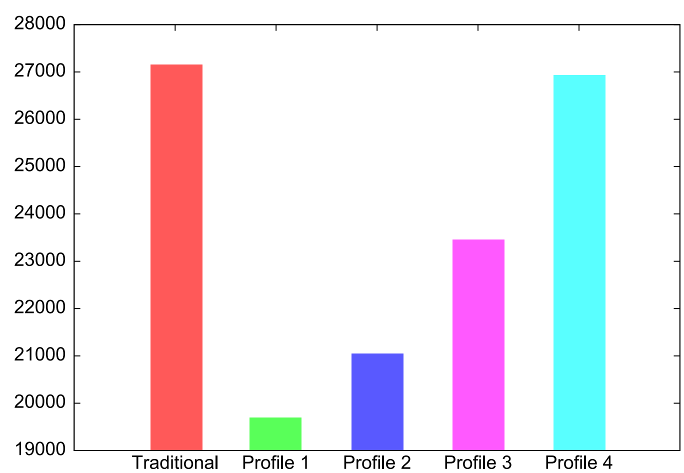

Fig 6. Energy consumption reducing the number of video streams.

The same energy consumption pattern can be identified in the graphics on Fig 5 and Fig 6. However, less energy is consumed for all configurations when there is only one source node streaming video, though differing in the absolute value of energy saving. Thus, although video streaming can be harmful for real-world wireless sensor network, transmission optimizations as proposed in this paper can be valuable to achieve energy savings while providing video content for an extended period of the network lifetime.

It is interesting to note that higher values of energy thresholds imply in energy savings that can be reflected in the increasing of the network lifetime. However, dropping low-relevant packets in early stages of the network may harm the overall monitoring quality of the application. This tradeoff between energy savings and monitoring quality require a clear understanding of the actual monitoring tasks of the network, the expected quality and intended network lifetime.

As a final comment, multimedia coding and compression tasks consume energy, memory and processing resources of the source nodes. In our simulations, however, we considered only the energy costs for packet transmission, since whatever the employed relaying approach, the energy consumption in source nodes will be the same.

V. CONCLUSIONS

We have proposed an adaptive energy-efficient multimedia streaming transmission where intermediate nodes relay data packets to the next hop based on their residual energy level and pre-configured energy thresholds. As the final monitoring quality depends on the context of the performed monitoring tasks, each application defines a monitoring profile directly indicating the relevance of each data type. The defined monitoring profiles will then be employed in critical intermediate nodes to define the relaying policy of data packets that must be adopted, saving energy when less relevant packets are silently dropped.

Some simulations were performed in order to assess the performance of the proposed approach in terms of energy consumption. The initial results indicated that the proposed adaptive multimedia streaming mechanism was suitable for optimizations in wireless multimedia sensor networks.

Future works will address simulations for different communication scenarios, relating network topologies with the resulting energy consumption. Furthermore, some numerical approach will be designed to assess the resulted monitoring quality when some packets do not reach the sink because of dropping in intermediate nodes. Doing so, a numerical resource will be available to verify the final monitoring quality depending on the considered energy thresholds, providing a valuable mechanism to adjust these parameters according to the expected QoS of monitoring applications in wireless sensor networks.

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