



# Mobile traffic modelling for wireless multimedia sensor networks in IoT



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## ABSTRACT

Wireless sensor networks suffer from some limitations such as energy constraints and the cooperative demands essential to perform multi-hop geographic routing for real-time applications. Quality of Service (QoS) depends to a great extent on offering participating nodes an incentive for collaborating. In this paper, we present a novel traffic model for a new-generation of sensor networks that supports a wide range of communication-intensive real-time multimedia applications. The model is used to investigate the effects of multi-hop communication on Intelligent Transportation Systems (ITS) via Markov discrete-time M/M/1 queuing system. Moreover, an analytical formulation for the bit error rate (BER), and the critical path-loss model is presented. We address the degree of irregularity parameter for location-based switching with respect to two categories in distributed retransmission: the hop-by-hop and the end-to-end retransmission. Simulation results based on realistic case study and assumptions are performed to highlight the effects on the average packet delay, energy consumption, and network throughput. The findings presented in this work are of great help to designers of wireless multimedia sensor networks (WMSNs).

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## 1. Introduction

Wireless Sensor Networks (WSNs) are one of the key enabling technologies for IoT applications that help in gathering and providing the requested information from the environment to the user [1,3]. IoT applications aim mainly at utilizing the most advanced communication technologies in order to provide smart services for citizens in several fields such as healthcare, public safety, and transportation. In order to build such a smart paradigm, a huge number of IoT devices (sensors) should be deployed to gather and deliver the massive amount of data through the network [2]. These devices are equipped with storage, communication, computing, and sensing (imaging) capabilities to enable the network elements to communicate multimedia messages with each other and with the end-users [4]. Multimedia sensing is facing many challenges such as energy consumption, cost, and the inability of the current wireless network infrastructure to deal with its huge amounts of data traffic.

For the first challenge, as much as we increase the number of deployed sensors, they consume much more energy to work and

this can increase the costs of energy, also the reality that most of the sensors are working with batteries and more energy consumption can make sensor nodes run out of energy quickly and causing death for these nodes, as a result, the connectivity of the network may badly be affected. For the second challenge, deploying huge numbers of sensors will increase the hardware cost of the network, and the network will not be financially affordable to be applied. Thirdly, in dense sensing, gathered data will be in huge amounts and the current wireless network infrastructure like 3G or 4G can't contain these amounts of data. For instance, Solmaz and Turgut [18] propose an emergent and pedestrian tracking system where they use opportunistic ad hoc communications to track and evacuate pedestrians in case of a disaster. In this model, pedestrians' smart phones store and carry messages to a number of mobile sinks, which are responsible for communicating with smart phones and getting to the emergent location effectively.

However, IoT applications convey new design challenges for WSNs. Energy consumption, storage management, heterogeneity of devices and communication bandwidth are some of the major challenges facing this emerging IoT paradigm [22]. So far, WSNs have only been designed to serve application-specific needs. But in the IoT paradigm, they need to provide an application platform with heterogeneous sensors that multiple users can access to gather information about different phenomena, at different in-

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stants of time, from different parts of the network. The heterogeneity in sensing devices and user requests generates heterogeneous multimedia traffic flows in the network, which is very difficult for the energy constrained sensor network to manage. The operation of inefficient design of the antenna is one of those design issues which significantly exhausts most of the battery-life of the sensor node. Consequently, it might adversely affect the wireless channel and lead to error-prone links and inefficient routing [6]. Presence of low power-receive states as well as application-specific protocols such as LORA and ZigBee can potentially limit the battery-draining activity and improve the network performance.

Meanwhile, traffic access to the media from the distributed sensor nodes should be strictly controlled to avoid redundancy and collisions, which have a dramatic impact on the lifetime of the wireless multimedia sensor networks (WMSNs) [6]. WMSNs can be used to aggregate multimedia traffic load and relay to the back-haul Internet in IoT or other access networks. Unless it is planned carefully this can result in extensive amounts of energy consumption. Considerable amounts of energy can be wasted unless an appropriate traffic modelling is considered for the WMSN nodes which are deployed to serve static/mobile users in IoT environments. Therefore, an accurate traffic modelling strategy is required to predict the performance of the system especially in terms of energy consumption. This would not be achieved without a realistic case study analysis and an accurate analytical model that can predict the system performance under such setups.

In this paper, a systematic model is proposed for an upcoming multimedia routing technique, which finds the optimal quality of service (QoS)-based path [8]. This model examines the effects of Multi-Hop Communication (MHC) while deriving a closed form for the bit-error-rate (BER). To manage the performance of energy consumption and QoS factors, the WMSN topology should match the actual surrounding setups. Consequently, an unwarranted path-loss model for adaptive switching between two types of transmission structures is designed. Effective path-loss model is considered based on a Markov discrete-time M/M/1 model and applied to the WMSN duty-cycled nodes. Surrounding environment-specific metric in the path-loss model, called the degree of irregularity (DOI), has been considered. It is a function of the distance between two nodes. The adaptive switching mentioned above occur with respect to DOI. The DOI is used to determine which path will be used to send a packet from the source node to the next hop. The analysis of the energy consumption, delay, and throughput can be then used to optimize data routing protocols in WMSNs. And thus, the main contribution of this paper is the development of a framework for analyzing the optimal forwarding choices with respect to QoS parameters, while quantifying the impact of the relay of radio irregularity at the MAC layer in two transmission schemes.

The remainder of this paper is organized as follows. In Section 2, an overview of previous analyses of MHC schemes in WMSNs is provided. System models and Markov queuing model for multimedia routing are introduced in Section 3. In Section 4, a practical use case is provided, and simulation results for the discussed models are presented. In Section 5, the use case performance is evaluated and assessed. Finally, the concluding remarks are summarized in Section 6.

## 2. Related work

Recently, there have been several IoT projects such as smart cities, healthcare and smart streets' lighting which are seeking ways to integrate three functions: sensing, processing, and communicating, into a single integrated circuit for various real-time applications with limited energy consumption [5]. Moreover, research about how all these critical processes are going to function together is underway. Oteafy and Hassanein [19] analysis the

fundamental issue of component interaction and operation under the IoT umbrella. Furthermore, studies focusing on new techniques, such as cooperative multilayer communication among nodes and network coding for wireless communication using particle-sized sensor nodes that are distributed for wide-area sensing have been proposed in [9]. However, the increased interest in real-time applications in multimedia sensor networks have lead these studies to focus on enhancing the network performance by relying on an accurate link estimation in order to assure efficient use of energy resources in the sensor node. Cross-layer awareness is considered as a potential solution to various issues and a way to improve the performance in WMSNs because of the possibility of involving both the PHY and MAC layers to provide functions other than routing, such as the power efficiency. On this note, we can decide to use asynchronous medium access control (X-MAC) duty-cycled protocols, instead of synchronized one, since X-MAC have lower packet latency and higher energy efficiency due to their reduced idle listening [17].

Recently, lots of research attempts have been carried out by many researchers on the modeling of WMSNs traffic to investigate the performance of the network. These attempts can be classified into the following classes; static, dynamic, and hybrid [21]. In static modelling approach, WMSN nodes are installed in indoor environments such as inside a home or office building, shopping malls, airports, to improve indoor connectivity and enhance the users' internet experience [12,14,16]. In dynamic modelling approach, unlike the static one, sensor nodes are not static and they are deployed in moving vehicles to provide services to mobile users. For example sensor nodes can be installed in public transportation vehicles such as busses and trains to enhance coverage and internet connectivity while on the move [5–7,19]. A number of cooperative/hybrid methods have been used also in WMSNs to model the network performance. These methods are mostly classified as either cooperative ARQ protocols or conversion from single-hop to multi-hop transmission protocols. Antonopoulos and Verikoukis [10] propose a Network-Coding-based Cooperative ARQ MAC procedure for WSN (NCCARQ). This protocol focuses on a centralized WMSN system that manages the retransmission of channel access that provide bidirectional connection between sensor nodes. Every sensor node stores a copy of the packet that has been received, until they receive a positive acknowledgment from the sink, otherwise, the error mechanism completes an error check on the received message. Therefore, CSMA-based protocol forms a well-match with the IEEE 802.15.4 standard. Additionally, this compatibility enables the NC-CARQ to use the same style to control the packets and follow the same standards, but with added adjustments to enhance the efficiency of the proposed protocol [20]. It is similar to the model proposed in this paper, where, it uses less control packets than the ARQ-based protocol, with efficient energy use and fulfilling QoS parameters.

A typical ad-hoc network operates according to a cooperative multi-hop transmission approach, which achieves greater power efficiency because it operates at a low signal-to-noise-ratio (SNR) that is needed to cover the transmission range. Stanojev et al. [11] adopted the linear multi-hop transmission approach by considering quasi-static fading without spatial reuse. This adaptation simplified the linear multi-hop transmission approach by including Hybrid Automatic Repeat Request (HARQ) retransmission protocols. The authors focused on a design that provides the optimal number of hops with a maximum delay along a linear multi-hop network that achieves maximum end-to-end throughput. This analytical framework allows the parameters to be set as an optimization problem, which is solved using numerical methods. Likewise, Sikora et al. [12] considered an uncooperative linear approach for multi-hop and single-hop network transmission (in which the nodes do not cooperate and attempt to access the channel simulta-

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