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# Estimating the Impact of Adding Sensor Nodes to Biomedical Wireless Sensor Networks

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**Abstract.** Biomedical wireless sensor networks enable the development of real-time patient monitoring systems, either to monitor chronically ill persons in their homes or to monitor patients in step-down hospital units. However, due to the critical nature of medical data, these networks have to meet demanding quality of service requirements, ensuring high levels of confidence to their users. These goals depend on several factors, such as the characteristics of the network deployment area or the network topology. In such context, this work proposes a method to find the best network physical topology in order to maximise the quality of service provided by the network. The proposed method makes use of "virtual sensor nodes" to estimate the impact of adding real sensor nodes to the network in a specific location. Thus, assessing different locations, it is possible to find the best location to place the new sensor node while maximising the quality of service provided by the network. In particular, this work studies the feasibility of using "virtual sensor nodes" to assess the impact of adding a new sensor node to a biomedical wireless sensor network and presents some results showing the viability of the proposed method.

**Keywords:** Biomedical Wireless Sensor Networks; Quality of Service.
**PACS:** 89.20.Ff

## INTRODUCTION

Biomedical Wireless Sensor Networks (BWSNs) are small-sized networks of wirelessly connected biomedical sensors designed for medical applications or healthcare services. Typical applications of BWSNs include ambient assisted living systems to monitor and assist disabled or elderly people, and patient monitoring systems to monitor chronically ill persons, either in their houses or in step-down hospital units. In particular, the focus of this work goes to the Quality of Service (QoS) guarantees imposed by patient monitoring systems to BWSNs when collecting vital and physiological signs of patients in step-down hospital units.

The ability of a BWSN to provide the requested QoSdepends on several factors, including: the characteristics of the BWSN deployment area and the BWSN topology. In fact, as far as harsh environmentsare concerned, these two factors are closely related. Harsh environments, like hospital facilities, can expose BWSNs to very hostile situations regarding the wireless communications and, therefore, compromising the communications among the network nodes.If the worst comes to the worst, the links between the network nodes can be broken and, as a consequence, the network topology can often change, compromising the QoS being provided.In such scenario, it is important to choose the most favourable locations to place the sensor nodes in order to minimise the network's vulnerability to such hostile environments and at the same time maximising the BWSN's ability to provide the requested QoS.

## BWSN REPRESENTATIVE SCENARIO

The suggested method was developed with the following scenario in mind: inside a hospital step-down unit several patients are being monitored; the patient monitoring system uses a BWSN to carry the data, gathered from each patient, to a central database.Under these conditions, the BWSN supporting the communications of the patient monitoring system must ensure the requested QoS, regardless the hostile conditions of the network deployment environment. Thence, the healthcare providers face a major problem, namely: how to choose the most favourable position to place the patients (i.e., the BWSN's sensor nodes) in order to maximise the BWSN's ability to supply the required QoS.

In view of this representative scenario, the proposed method uses "virtual sensor nodes" to mimic the presence of new patients within the BWSN in order to estimate their impact on the QoS being provided by the BWSN and find the answer to the former question.

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# PROPOSED METHOD

The proposal of this work is that, a “virtual sensor node” can simulate the presence of a real sensor node placed on its neighbourhood, producing the same impact on the QoS being provided by the network. In this way, from the network point-of-view, to simulate the behaviour of the real sensor node, the “virtual sensor node” has to generate data traffic with the same characteristics as the one generated by the real sensor node.Therefore, the scenarios a) and b) pictured in FIGURE 1 can be considered equivalent.

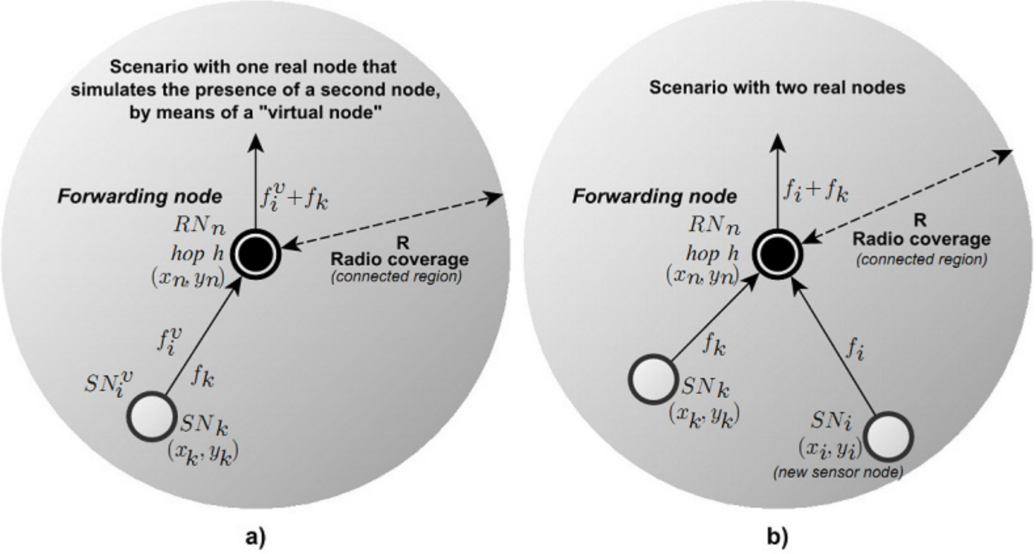

**FIGURE 1. a)** A real sensor node simulating the presence of a new sensor node, and **b)** the new sensor node already within the network.

To clarify the proposed idea, let’s consider FIGURE 1. The left side scenario shown in FIGURE 1 (i.e.,FIGURE 1 a)) represents a real sensor node (i.e., the $SN_k$) and a “virtual sensor node” (i.e., the $SN_i^v$) created by the $SN_k$, the latter simulating the presence of a new sensor node in its neighbourhood. Each one of those two sensor nodes generates its own data flow: the $SN_k$ generates the data flow $f_k$ and the $SN_i^v$ generates the data flow $f_i^v$. On its turn, the scenario represented on the right side of FIGURE 1 (i.e., FIGURE 1 b)) portraits the real scenario in which the “virtual sensor node” was replaced by the new real sensor node (i.e., the $SN_i$). Our proposal is that, if the data flow $f_i^v$ as the same characteristics of the data flow $f_i$, then, such scenarios can be considered equivalent.

Looking to FIGURE 1, one of the principal differences between the two scenarios presented are the different locations of the sensor nodes $SN_i^v$and $SN_i$. As a consequence, the data flows $f_i^v$ and $f_i$ may reach the $RN_n$ with different delivery probabilities (n.b., the signal strength decays exponentially with respect to the distance between the nodes that are communicating. Moreover, for a given transmitter-receiver distance $d$, the signal strength is randomly distributed among the mean distance dependent value [1]). However, some studies suggest that sensor nodes that are geographically close to each other may have high spatial correlation in their Packet Reception Ratios(PRRs) [2]. Moreover, several experimental studies performed during the last few years have shown that the wireless links in real deployments can be found in one of three regions, namely connected, transitional, and disconnected [1] [2] [3]. The links within the connected region are often of good quality, stable and symmetric. On the other hand, the links in the transitional region are of intermediate quality (n.b., considering a long-term assessment), unstable, not correlated with the distance between the transmitter and the receiver, and a lot asymmetric. Finally, within the disconnected region, the links have poor quality and are inadequate to support communications [3]. In view of these outcomes it is possible to make the following observations to support the proposed methodology: 1) sensor nodes within the connected region have high PRRs; 2) sensor nodes geographically close to each other may have high spatial correlation in their PRRs.Therefore, the scenarios presented in FIGURE 1 can be considered equivalent if both the “virtual sensor node” (i.e., the $SN_i^v$) and the new real sensor node (i.e., the $SN_i$) are located inside of the connected region.

# MATHEMATICAL FRAMEWORK

A key requirement of the proposed method is that the sensor nodes must be located inside the connected region. The authors of [3] have identified the parameters that influence the length of the connected region. Among the parameters identified, the transmitter output power is of utmost importance. It can be easily used to tune the limits of the connected region, according to the needs of each specific application, taking into consideration the particular characteristics of each network deployment area. Thus, in the following, has provided an example about how to find the minimum transmitter output power to achieve a desired length of the connected region.

Then, in order to fundament the proposed method, it will be analysed at two levels. First, at the node level, the effects of positioning the sensor nodes at different locations were investigated in view of single-hop communications. In particular, at the first hop count from the sensor node to the sink. Then, the effects of having different delivery probabilities of single-hop communications are studied at the network level, i.e., considering the multi-hop communications. Our analyse does not consider sensor node's mobility nor dynamic objects in the deployment environment, and the channel conditions for each wireless link are considered to be constant along the time, or at least during significant time intervals.

## Finding the Minimum Transmitting Power for the Envisioned Scenario

In the following we assume NRZ encoding and consider noncoherent FSK modulation schemes used in TelosBmotes. This analysis uses the log-normal shadowing path loss model [4] and the outcomes presented in [3] to find the minimum transmitting power, $P_t$, necessary to achieve a connected region with a radius of 5 m. The parameters used to model the indoor environment are: path loss exponent $\eta = 3$; standard deviation $\sigma = 4$; power decay at the reference distance $d_0$, $PL(d_0) = 55$ dB; noise floor $P_n = -105$ dBm; and the size of the frames used to communicate is $f = 70$ bytes.

Let us bound the connected region to PRRs greater than 0.9 and the transitional region to PRRs between 0.9 and 0.1. From the theoretical model deduced in [3], we obtain the following SNR values for PRRs of 0.1 and 0.9, $\gamma_{L\,dB}$and $\gamma_{U\,dB}$, respectively,

$$\gamma_{L\,dB} = 10\log_{10}\left(-1.28\ln\left(2\left(1-0.1^{\frac{1}{8f}}\right)\right)\right) \approx 7.9 \text{ dB},$$

$$\gamma_{U\,dB} = 10\log_{10}\left(-1.28\ln\left(2\left(1-0.9^{\frac{1}{8f}}\right)\right)\right) \approx 10.0 \text{ dB},$$

and we have

$$P_t = P_n + \gamma_U + PL(d_0) + 2\sigma + 10\eta\log_{10} d_s \approx -11 \text{ dBm}$$

for the minimum transmitting power necessary to achieve the necessary length of the connected region.

In the following sections we analyse if a “virtual sensor node” can simulate the presence of a real sensor node placed in the connected region of 5 m in length.

## Analysing the Proposed Method Considering Single-hop Communications

Consider the scenario presented in FIGURE 1. To obtain the maximum difference between the PRR achieved both by the virtual data flow $f_i^v$ and by the real data flow $f_i$, considering only first-hop (i.e., the link between the $SN_i^v$, or the $SN_i$, and the $RN_n$), we use the equation of PRR at a transmitter-receiver distance *d* obtained in [3]:

$$p(d) = \left(1 - \tfrac{1}{2}\exp\left(-\tfrac{\gamma(d)}{1.28}\right)\right)^{8f}, \tag{1}$$

where $\gamma(d)_{dB} = P_{t\,dB} - PL(d)_{dB} - P_{n\,dB}$, $PL(d)_{dB} = P_{t\,dB} - P_{r\,dB}$ , and $P_{r\,dB}$ is the received signal strength at a given distance *d* from the transmitter. From [4] we have $PL(d) = PL(d_0) + 10\eta\log_{10}(d/d_0) + X_{0,\sigma}$, where$X_{0,\sigma}$ is a zero-mean Gaussian random variable (in dB) with the standard deviation $\sigma$ (shadowing effects). First, we obtain a relationship between $p(d_{i,n})$and $p(d_{i,n} + \Delta d_{i,n})$ for an increment $\Delta d_{i,n}$ at the distance $d_{i,n}$ between $SN_i$and $RN_n$. Using theTaylor’s theorem for the case $n = 1$ at the point $d_{i,n}$, we have:

$$p(d) = p(d_{i,n}) + \dot{p}(d_{i,n})\Delta d_{i,n} + R_{i,n}, \tag{2}$$

where$R_{i,n}$ is the remainder term. By the properties of(1) we can state that the remainder term $R_{i,n}$ is residual in the interval $]0,5]$ and (2) with $R_{i,n} = 0$ is a good linear approximation to (1)on$]0,5]$. Then, we have $p(d_{i,n} + \Delta d_{i,n}) - p(d_{i,n}) = \dot{p}(d_{i,n})\Delta d_{i,n}$, where

$$\dot{p}(d_{i,n}) = -\frac{8f\alpha\beta\eta}{2.56 d_{i,n}}\left(1 - \frac{\alpha}{2}\right)^{8f-1}, \tag{3}$$

$\alpha = \exp(-\beta/1.28)$and $\beta = 10^{(P_t - PL(d_0) - 10\eta\log_{10}(d_{i,n}) - P_n)/10} = 10^{3.9 - 3\log_{10}(d_{i,n})}$. Since (3) is a decreasing non-positive function, we obtain that$\max_{d_{i,n}\in]0,5]}|\dot{p}(d_{i,n})| = |\dot{p}(5)|$. Thus, we obtain $|\dot{p}(d_{i,n})| \leq 2.3 \times 10^{-18}$. Therefore, since $\Delta d_{i,n} \in ]0,5]$, we have $|p(d_{i,n} + \Delta d_{i,n}) - p(d_{i,n})| \leq 1.2 \times 10^{-17} \approx 0$ in the connected region of 5 m in length. Thus, the difference between the PRR achieved both by the virtual data flow $f_i^v$ and by the real data flow $f_i$, considering only the first-hop, is approximately equal tozero.

## Analysing the Proposed Method Considering Multi-hop Communications

Typical BWSNs have multiple hops between the source sensor nodes and the sink. In fact, they may have not only several hops between those nodes, but also several paths to route the data gathered by the sensor nodes to the sink. In that way, two sensor nodes can send their data to the sink using distinct data paths, each one having a particular PRR associated. In our proposal, we consider that the data flow $f_i^v$, generated by the “virtual sensor node”$SN_i^v$ of FIGURE 1 a), follows the best path to reach the sink (n.b., the rule to find the best path depend on the routing protocol in use). Moreover, the sensor node $SN_i$ will use the same path to send its data to the sink. In other words, we are assuming that both the “virtual sensor node”, $SN_i^v$, and the real sensor node, $SN_i$, use the same data path to send their data to the sink. In this way, the PRR associated with the path between the $RN_n$ and the sink is the same for both data flows.Additionally, as was shown in the last subsection, the PRRs achieved both by the virtual data flow $f_i^v$ and by the real data flow $f_i$ at the first hop are similar. Consequently, it is possible to argue that the PRRs of both data flows, for the entire path (i.e., from the sensor node until the sink) are equivalent.

## CONCLUSIONS

Biomedical wireless sensor networks used to support the communications of patient monitoring systems have to fulfil high levels of quality of service in order to be accepted and used on a daily base. In fact, one of the problems faced by nursing staffs managing patient monitoring system is to find the best location to place new patients while maximizing the quality of service provided by the network. In such context, this work proposes the use of “virtual sensor nodes” to estimate the impact of adding real sensor nodes (i.e., new patients to be monitored) to the network. The results achieved analytically, using the log-normal shadowing path loss model, suggest that the proposed method can be used to simulate the presence of a new real sensor node within a biomedical wireless sensor network and, therefore, estimate its impact on the quality of service being provided by the network.

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## REFERENCES

1. M. Younis and K. Akkaya, “Strategies and techniques for node placement in wireless sensor networks: A survey”, *Ad Hoc Networks***6**(4), 621-655 (2008).
2. N. Baccour et al., “Radio link quality estimation in wireless sensor networks: A survey”, *ACM Trans. Sen. Networks***8**(4), 34:1-34:33(2012).
3. M. Zuniga and B. Krishnamachari, “Analyzing the transitional region in low power wireless links” in *Sensor and Ad Hoc Communications and Networks*, First Annual IEEE Communications Society Conf. on IEEE SECON 2004, 517-526 (2004).
4. T. S. Rappapport, *Wireless Communications: Principles and Practice (2nd Edition)*, Prentice Hall, 2002.