Modulated Backscattering Coverage in Wireless Passive Sensor Networks

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Abstract: *A wireless sensor network (WSN) is a wireless network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations. During RF transmission energy consumed by critically energy-constrained sensor nodes in a WSN is related to the life time of the system as life time of the system is inversely proportional to the energy consumed by energy sensors. In modulated backscattering (MB) sensor nodes send their data just by switching their antenna impedance and reflecting the incident signal coming from an RF source. So wireless passive sensor networks (WPSN) designed to operate using MB do not have the lifetime constraints. So MB is a promising design. In this we are going to investigate the system analytically. To obtain interference-free communication connectivity with the WPSN nodes number of RF sources is determined and analyzed in terms of output power and the transmission frequency of RF sources, network size, RF source and WPSN node characteristics. System life time of wireless sensor networks (WSN) is inversely proportional to the energy consumed by critically energy-constrained sensor nodes during RF transmission. In that regard, modulated backscattering (MB) is a promising design choice in which sensor nodes send their data just by switching their antenna impedance and reflecting the incident signal coming from an RF source. Hence, wireless passive sensor networks (WPSN) designed to operate using MB do not have the lifetime constraints of conventional WSN. However, the communication performance of WPSN is directly related to the RF coverage provided over the field the passive sensor nodes are deployed.*

Keywords: Sensor networks, wireless passive sensor networks, modulated backscattering, communication coverage.

1. Introduction

Wireless sensor networks (WSN) are, in general, composed of low-cost, low-power sensor nodes which can only be equipped with a limited power source, i.e., a battery. Sensor nodes consume most of the stored power during RF transmission. At this point, modulated backscattering (MB) is a promising communication technique leading to a new sensor network paradigm, Wireless Passive Sensor Networks (WPSN). WPSN are supplied with energy by external RF power sources. With MB approach, a passive sensor node transmits its data simply by modulating the incident signal from an RF source by switching its antenna impedance. Therefore, the transmitter is basically an antenna impedance switching circuitry, and WPSN is free of the lifetime constraint of conventional WSN.
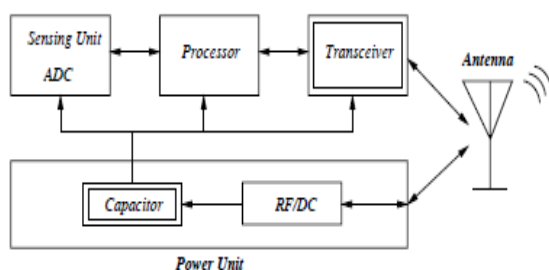

Figure 1: WSN node

As in WSN, to meet application requirements, event characteristics must be reliably sensed and communicated via collective operation of sensor nodes to remote sink in WPSN. RF sources receive the signal reflected from sensor nodes, and they should send the gathered data to the sink without causing any interference in the network. Therefore, in order to maintain the communication connectivity and RF coverage without compromising the communication reliability due to possible interference, it is important to carefully design the WPSN deployment, especially the number of RF sources. The main focus of this paper is to investigate the communication coverage problem in WPSN. More specifically, minimum number of RF sources to achieve successful MB based communication in WPSN is investigated. Furthermore, the relation between the numbers of RF sources that are required to obtain interference-free RF communication coverage is analyzed in terms of output power and the transmission frequency of RF sources, network size, RF source and WPSN node characteristics. The results of this paper reveal that communication coverage can be practically maintained in WPSN through careful selection of design parameters.

2. Literature Survey

2.1 Wireless Sensor Networks

A wireless sensor network (WSN) is a wireless network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations.

A WSN can be defined as a network of devices, denoted as *nodes*, which can sense the environment and communicate the information gathered from the monitored field (e.g., an area or volume) through wireless links The data is forwarded, possibly via multiple hops, to a *sink* (sometimes denoted as *controller* or *monitor*) that can use it locally or is connected to other networks (e.g., the Internet) through a *gateway*. The nodes can be stationary or moving. They can be aware of their location or not. They can be homogeneous

or not. This is a traditional single-sink WSN (see Figure 2, left part). Almost all scientific papers in the literature deal with such a definition. This single-sink scenario suffers from the lack of scalability: by increasing the number of nodes, the amount of data gathered by the sink increases and once its capacity is reached; the network size cannot be augmented. Moreover, for reasons related to MAC and routing aspects, network performance cannot be considered independent from the network size.

A more general scenario includes multiple sinks in the network .Given a level of node density; a larger number of sinks will decrease the probability of isolated clusters of nodes that cannot deliver their data owing to unfortunate signal propagation conditions. In principle, a multiple-sink WSN can be scalable (i.e., the same performance can be achieved even by increasing the number of nodes), while this is clearly not true for a single-sink network. However, a multi-sink WSN does not represent a trivial extension of a single-sink case for the network engineer. In many cases nodes send the data collected to one of the sinks, selected among many, which forward the data to the gateway, toward the final user (see Figure 2, right part). From the protocol viewpoint, this means that a selection can be done, based on a suitable criterion that could be, for example, minimum delay, maximum throughput, minimum number of hops, etc. Therefore, the presence of multiple sinks ensures better network performance with respect to the single-sink case (assuming the same number of nodes is deployed over the same area), but the communication protocols must be more complex and should be designed according to suitable criteria.
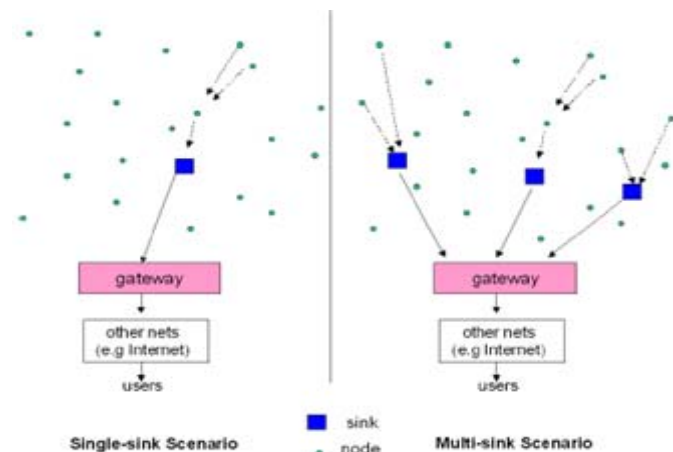

Figure 2: Left part: single-sink WSN. Right part: multi-sink scenario.

2.3 Applications of WSN

The variety of possible applications of WSNs to the real world is practically unlimited, from environmental monitoring, health care, positioning and tracking, to logistic, localization, and so on. A possible classification for applications is provided in this section. It is important to underline that the application strongly affects the choice of the wireless technology to be used. Once application requirements are set, in fact, the designer has to select the technology which allows satisfying these requirements. To this aim the knowledge of the features, advantages and disadvantages of the different technologies is fundamental.

Owing to the importance of the relationship between application requirements and technologies, we report in this Section some example requirements and we devoted Sections 5 and 6 to an overview of the main features of the most promising technologies provided for WSNs.

2.4 WPSN Model

Wireless passive sensor network proposed in this study is based on MB. The source of energy is an RF power source which is assumed to have unlimited power. The source transmits RF power to run the passive nodes, and it transmits and receives information from WPSN nodes simultaneously. A typical WPSN node hardware is represented in Figure 1. The WPSN node hardware differs from the conventional WSN hardware basically on the power unit and the transceiver. In a conventional WSN node, the power unit is a battery. In the WPSN node, however, the power generator, which is an RF -to-DC converter, is an inherent part of the power unit and is the unique power source of the sensor node. Required power is obtained from the incident RF signal inducing a voltage on the receiver WPSN node. Then, as long as 100mV of voltage is induced on the receiving antenna , RF-to-DC converter yields DC power which is either used to wake up and operate the receiver, sensing and processing circuitries of sensor node, or kept in a charge capacitor to be used later. The transceiver of a conventional WSN node is typically a short range RF transceiver. Compared to the other units of the node, the power consumption of the transceiver is considerably high. For this reason, in WPSN, MB, a passive and less power consuming method is adopted as the main communication mean. Here, the incident signal from the RF source is reflected back by the WPSN node. The node modulates this reflected signal by changing the impedance of its antenna, thereby transmits the data gathered from its sensing unit and processed by its processing unit, back to the RF source. The transceiver for MB is much less power consuming and fewer complexes, compared to conventional RF transceivers. Furthermore, the maximum communication range of MB is determined by the intensity of the incident signal, and the sensitivity of the corresponding receiver. Thus, long range communication with the WPSN node is theoretically achievable without increasing the power consumption of the node. In a WPSN deployment, let Pr and Pt be the received power on the passive sensor node and the transmitted power by the RF source, respectively. Then, the RF signal propagates according to Friis' transmission equation

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R_{rf}} \right)^2 \text{----------- (1)}$$

where Gt and Gr are the antenna gains, λ is the wavelength, i.e., the ratio of the speed of light c to the frequency f, and Rrf is the distance between the RF source and WPSN node. Let the voltage induced on the antenna of WPSN node due to incident signal from RF source be Vt. Then, the relation between the received RF power Pr and the induced voltage level Vt is expressed as [4]

$$P_r = \frac{\left| V_t^2 \right|}{8(R_r + R_t)} \text{----------------(2)}$$

where Rr and Rl are the impedances of the antenna of WPSN node and the RF source, respectively. According to (1) and

(2) and for *4W* effective isotropic radiated power (EIRP) output power of RF source, $R_r=R_t=50\Omega$, $G_tG_r = 8.5dBi$; it is calculated that $100mV$ can be induced on the antenna of WPSN node from $6.75m$ at $2GHz$, $13.49m$ at $1GHz$, and $26.98m$ at $500MHz$, respectively. These calculated range values clearly demonstrate that multiple RF sources are needed for the practical implementation of a WPSN deployed over a large event area. Therefore, the required number of RF sources, for a given network size and communication parameters, needs to be determined for sufficient RF coverage, and hence, effective communication in WPSN.

3. Communication Coverage

N sensor nodes are assumed to be randomly distributed over an event area of size Δ. Communication range of each RF source is represented by a circle of radius R_{rf}. The RF-to- DC converters of WPSN nodes in the range of an RF source are successfully activated by the source, and hence, they are able to reflect the collected data back to the RF source. Here, the ranges of RF sources are considered to be non-overlapping to avoid interference between adjacently deployed RF sources. Source-to-source interference is illustrated in Figure 3(a). Receiving both the reflected signal from the WPSN node and the strong signal from the source S_1 causes interference at source S_2. Similarly, source-to-node interference is shown in Figure 3(b). Communication with two RF sources simultaneously causes interference at the WPSN node *k*. In both cases, communication reliability is hampered due to loss and channel errors. Therefore, in order to avoid these two types of interference, RF sources must have non-overlapping circular ranges of R_{rf} in this analysis. Thus, each passive node is fed by only one RF source in this case.
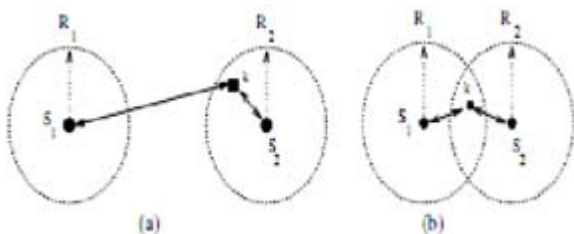

Figure 3: (a) Source-to-source interference, (b) source-to-node interference

Note that, in fact, if WPSN nodes were fed by multiple RF sources, passive sensor nodes would be able to store more energy in a faster way, and it would be easier for the nodes to receive, store, and transmit power, which would reduce the required number of RF sources for successful communication coverage. Therefore, non-overlapping RF source ranges lead us to the worst-case analysis in this case. Let *k* be the required number of RF sources to provide MB based communication coverage over the entire event area of size Δ. Then,

$$k = \frac{\Delta}{\pi R_r^2 f} \text{----------------------}(3)$$

where R_{rf} is the communication range of an RF source. Substituting (3) for R_{rf} into (1), and then using (2), the required number of RF sources for communication coverage in WPSN, i.e., *k*, can be obtained as

$$k = \frac{2\pi\Delta f^2 \left|V_t^2\right|}{c^2 P_t G_t G_r (R_r + R_l)} \text{--------------}(4)$$

where *f* is the carrier frequency of the RF source, *c* is the speed of light *c*, i.e.,

$$\lambda = c/f$$

Consequently, (4) can be used to determine appropriate design parameters for effective communication coverage in WPSN as will be shown next.

4. Hardware Analysis

The current practice in wireless sensor networks (WSNs) is to develop functional system designs and protocols for information extraction using intuition and heuristics, and validate them through simulations and implementations. We address the need for a complementary formal methodology by developing nonlinear optimization models of static WSN that yield fundamental performance bounds and optimal designs. We present models both for maximizing the total information gathered subject to energy constraints (on sensing, transmission, and reception), and for minimizing the energy usage subject to information constraints. Other constraints in these models correspond to fairness and channel capacity (assuming noise but no interference). We also discuss extensions of these models that can handle data aggregation, interference, and even node mobility. We present results and illustrations from computational experiments using these models that show how the optimal solution varies as a function of the energy/information constraints, network size, fairness constraints, and reception power. We also compare the performance of some simple heuristics with respect to the optimal solutions. Main components of a WSN node;

- Controller
- Communication device(s)(transceiver)
- Sensors/actuators
- Memory
- Power supply

5. Result Analysis

5.1 Module Separation

This work involves four modules,

Module 1: Deriving equation for Pr & Pt
Module 2: Calculating Rf Source Output Power with respect to Pt
Module 3: Calculating Rf Source Output Power with respect to carrier frequency
Module 4: Calculating Rf Source Output Power with respect to the area of the event field

5.1.1 Module Description

Module 1
In a WPSN deployment, let Pr and Pt be the received power on the passive sensor node and the transmitted power by the RF source, respectively. Then, the RF signal propagates according to Friis' transmission equation

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R_{rf}} \right)^2$$

Module 2

Increasing the RF output power Pt means increasing the range Rrf (RF communication range). An event field can be covered by a smaller number of RF sources if the communication range of RF sources is increased. When k decreases with increasing Pt, and hence, increasing Rrf range. Moreover, this shows that k increases with carrier frequency for a specific Pt value. This is because WPSN nodes use more energy from RF sources when the communication rate is increased.

Module 3

For a given network dimension and RF output power, increasing carrier frequency mandates an increase in the number of RF sources. This is mainly because WPSN nodes become able to use a higher data switching frequency, hence a higher data rate, and the energy consumption for data communication increases. Furthermore, k can be reduced by increasing the output power at a given RF frequency. When output power is increased, the range of RF sources increases, and they start to transmit with higher energy. As a result, each RF source is able to communicate with more WPSN nodes, and a smaller number of RF sources are required for communication connectivity over the event field.

Module 4

When increasing the network size necessitates communication connectivity over a larger area, and this requires more RF sources, since the range of each RF source is limited by its output power.

5.2 Formulae and Equations Involved

(i) Pr=PtGtGr(λ/4ΠRrf) -------------------------(1)
     Pt = Transmitted power by the RF source
     Pr = Received power on the passive sensor node,
     GtGr = Antenna gains
     Rrf = communication range of an RF source.
(ii) Pr= ∣Vt2 ∣/(8(Rr+Rl))---------------------- (2)
     Vt2 = Incident signal from RF source.
     Rr+Rl = antenna impedance
(iii) k= Δ/(ΠR2rf)--------------------------------(3)
     k= Required number of RF sources to provide MB based communication coverage
     Δ= Event area of size
(iv) k= 2 Π Δ f2 ∣Vt2 /(c2PtGtGr(Rr+Rl))) ------(4)
     The above represents the final equation for calculating the number of RF sources required for interference free communication

5.3 Phase 1(Calculation of transmitted power and received power)

Consider any three induced voltage's in the range of 100 to 150. With this we can calculate the received power's Pr in equation 2. Through this i.e. with the help of Pr we are going to calculate transmitted power Pt in equation 1.
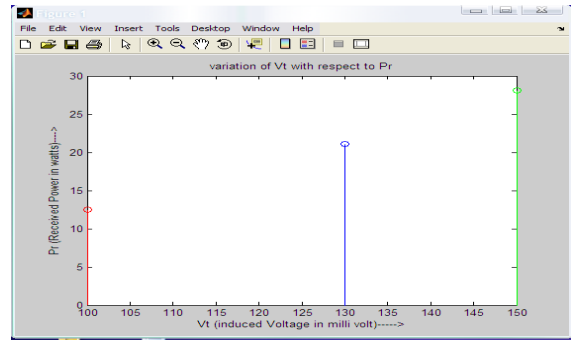

Figure 4: Graph between P_r, V_t

This shows the graph between Pr (Received Power),Vt (induced Voltage).

Calculated the Received Power (Pr) by using equation 2, by taking Vt= 100mv, 130mv, 150mv and observed the same values by using MAT LAB software.
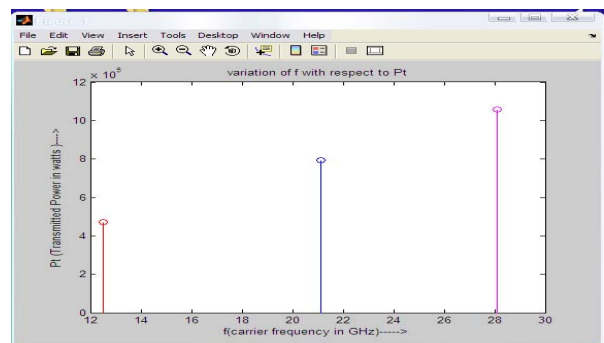

Figure 5: Graph for the calculation of Pr

This shows the graph between Pt(Transmitted Power),f (Carrier frequency). Calculated the Tranmitted Power (Pt) by using equation 1, by taking frequencies and observed the same values by using MAT LAB software.

5.4 Phase 2(Graphs Between K Vs Pt, K Vs Del, K Vs F)

Module algorithm: (for k versus pt)

Step 1: Calculate the antenna impedance with the given data's
Step 2: Find out the gain of the antennas with the given quantity
Step 3: Determine the field size
Step 4: Get the minimum induced voltage in the range of 100 to 150
Step 5: Get the RF frequency from the uhf range
Step 6: Then set the range of the transmitted power from 0.5 to 4
Step 7: through with the help of above parameters calculate the required number of RF Sources
Step 8: then simulate the results for various transmitted powers
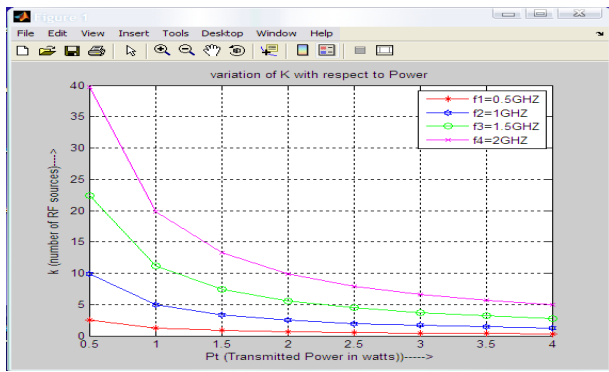Step 9: Analyze the results
Step 10: stop

Figure 6

In this section it was analyzed the number of RF sources (k), Transmitted Power (Pt), by taking carrier frequency (f) as constant. It can be observed that 'k' decreases, with increasing Pt, and hence, increasing Rrf range.
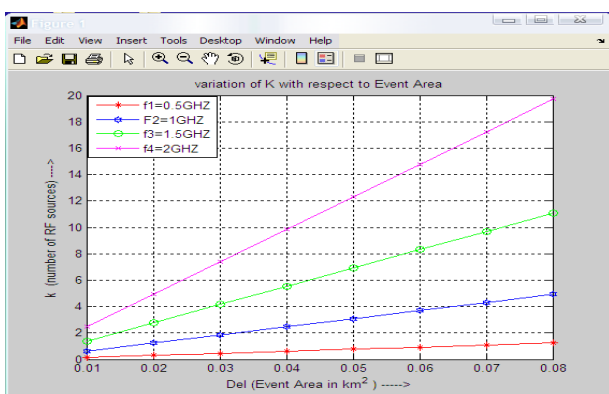

Figure 7

In this section it was analyzed the number of RF sources (k), Event Area (Del), by taking carrier frequency (f) as constant.
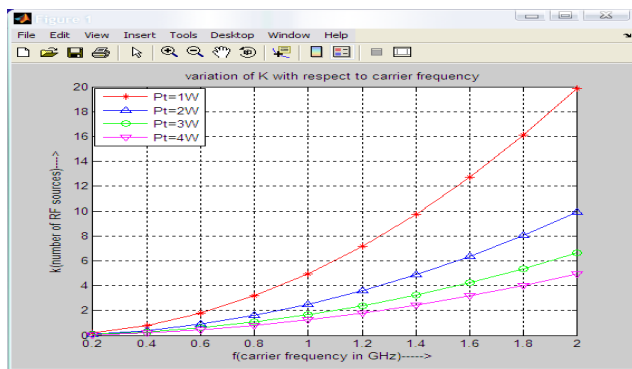

Figure 8

In this section we are going to analyze the number of RF sources (k), carrier frequency (f), by taking Transmitted Power (Pt) as constant.

K can be reduced by increasing the output power at a given RF frequency. When output power is increased, the range of RF sources increases, and they start to transmit with transmit higher energy. Increasing the size of the event field also increases the required number of RF sources for a given output power, because RF sources with a given output power have a limited range determined by their output power, and more such RF sources are needed to cover a larger area.

6. Conclusion and Future Scope

The analysis developed here can be used towards determination of design strategies of battery-free WPSN as well as radio frequency identification (RFID) networks. The communication coverage problem in WPSN was investigated. More specifically, minimum number of RF sources to achieve successful MB based communication in WPSN is investigated. Furthermore, the relation between the numbers of RF sources that are required to obtain interference-free RF communication coverage is analyzed in terms of output power and the transmission frequency of RF sources, network size, RF source and WPSN node characteristics. Sensor networks are an important emerging area of mobile computing that presents novel wireless networking issues because of their unusual application requirements, highly constrained resources and functionality, small packet size, and deep multi hop dynamic topologies. Although many high level architectural and programming aspects of this area are still being resolved, the underlying media access control (MAC) and transmission control protocols are critical enabling technology for many sensor network applications. These problems are well-studied for traditional computer networks, however, the different wireless technologies, application characteristics, and usage scenarios create a complex mix of issues that have led to the existence of many distinct solutions. It is natural to expect the low-level protocols to evolve again for this new era.

By using this investigated the communication coverage problem in wireless passive sensor networks (WPSN). More specifically minimum number of RF sources to achieve successful Modulated backscattering(MB) based communication in wireless passive sensor networks(WPSN) is investigated and the relation between the number of RF sources that are required to obtain interference free. In feature we can provide battery-free WPSN as well as radio frequency Identification (RFID) networks

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