Broadcast of Things – A Thought Experiment

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***Abstract*— Sensor networks as well as the Internet of Things, are getting more and more popular in many numbers of applications. However, a bidirectional link between the individual nodes is not always needed and leads to higher costs and power consumption. This paper introduces the concept Broadcast of Things which reverses the well known broadcast architecture. It is shown that in realistic environments the proposed concept of broadcasting sensor nodes offers an interesting alternative to usual sensor networks. By simulations the efficiency benefits of broadcasting sensor nodes is illustrated. To give an idea about the capability of the broadcast concept, a 1 cm^3 cubic demonstrator is shown. With a discussion and summary about the different efficiencies by the two concepts this paper is concluded.**

***Index Terms*—Broadcast of Things, efficiency, propagation model, sphere packing bound, wireless sensor networks**

I. Introduction

The concept of the Internet of Things (IoT) is getting more and more popular in wireless telecommunications. It envisages a dynamic network where everyday objects can interact with each other, sense the environment and potentially act on it [1]. Among others, potential applications are the transportation or healthcare domain, but also applications for controlling power grids (smart-grid). Enabling technologies for the IoT are techniques such as sensor networks based on the IEEE 802.15.4 standard family [2]. These standards are generally optimized for short data packets and low power consumption. However, a bi-directional communication is not required in many cases, e.g. when the devices act as pure sensors. Here, the sensors could simply broadcast their information, resulting in the concept of Broadcast of Things (BoT). It will be shown that this has certain advantages compared to classical bi-directional wireless sensor networks (WSN), e.g. improved battery lifetime and reduced complexity. Section II introduces this BoT concept. Section III presents the theoretical lower bound for signal energy and propagation models for BoT and multihop networks. Then, Section IV compares the performance of BoT and WSN w.r.t. the theoretical bounds. Section V shows a demonstrator for BoT, and Section VI concludes this paper.

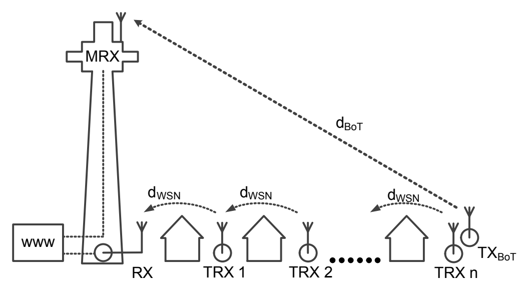

Fig. 1. BoT principal and WSN principal with n nodes and the different propagation conditions. For the BoT principal a receiver on a exposed poison like a television tower is shown.

II. The concept of "Broadcast Of Things"

BoT reverses the concept of classical broadcast as shown in figure 1. Thousands of tiny transmitter nodes (TX) transmit their data to one central mighty receiver (MRX). This central MRX can be e.g. positioned on a tower or church to cover large urban areas, where thousands of TXs are operating. As only a single receiver is required, this receiver can be very sophisticated, and hence, can operate close to the theoretical limits (section III-A) without significantly increasing the overall network costs. The MRX acts as a bridge between BoT and the internet (www), and so to the IoT. From the www the data of BoT can easily be accessed by human users via smartphones or tablet computers, actuators or other data processing systems. In contrast, the TX must be inexpensive in order to spread thousands of transmitters over a wide range of applications. Low power consumption is essential for a long time of operation, as the devices are powered with tiny batteries or small energy harvesters. However, only the small size opens many applications for BoT.

The main benefit compared to multihop WSN is, that the TX can be much simpler and cheaper. The BoT concept does not require any receiver inside the TX node and furthermore, no complex routing algorithms are necessary. The sum of these facts saves energy and simplifies the design. This makes the BoT approach interesting for low datarate, mid range sensor applications. Additionally, as introduced in next sections, in an urban area the BoT approach benefits from the different propagation conditions compared to a multihop WSN (section III-B).

III. Fundamentals

A. Theoretical lower bound for required signal energy

Shannon's sphere-packing bound describes the theoretical lower bound for the required E_b/N_0 on the RX side to decode a packet of k bits with a specified error probability [5]. Using a given power amplifier efficiency η_{TX}, the energy required (from the power supply) E_{TX} for a packet of k bits can be calculated along [4]:

$$E_{TX} = \frac{kFT_0 k_B L_P \left(\frac{E_b}{N_0}\right)}{\eta_{TX}}, \quad (1)$$

whereL_P is the path loss, F is the noise factor, $T_0 = 290K$ denotes the standard temperature, k_B is the Boltzmann constant E_b is the energy per bit, and N_0 is the noise spectral density. Typical E_b/N_0 values for state-of-the-art system-on-chip transceivers and high performance receivers are given in table I.

B. Propagation models

As shown in (1), the path loss L_P has direct influence on the required transmit power [6]. A realistic approximation for the path loss in a broadcast situation is given by the Okumura-Hata model [12], [13] or the ITU-R M.1225 guidelines for radio transmission [9], which match very well to each other. The measurement based Okumura-Hata propagation model [12], [13] is described as:

$$L_p(dB) = 69.55 + 26.16 \log f_c - 13.82 \log h_{bs} - a + (44.9 - 6.55 \log h_{bs}) \log d_{BoT}, \quad (2)$$

with the path loss L_p in dB, the carrier frequency f_c in MHz, height of base station (MRX) antenna h_{bs} in m, distance d_{BoT} in km and the environmental correction value a for the environment type.

As shown in [14], the Okumura-Hata and ITU-R model are not valid for WSN. The nodes in WSN are normally close to ground. Hence, the path loss is significantly higher compared to the broadcast channel model [12], [13]. A suitable measurement-based path loss model with Non-Line-of-Sight (NLOS) conditions for $900\,\mathrm{MHz}$ is presented in [8]. The results of [14] (extrapolated to $900\,\mathrm{MHz}$) and [8] show similar trends for path loss, and will be used in this paper:

$$L_p(dB) = L_p(d_0) + 10\alpha \log(d_{WSN}/d_0) + c, \quad (3)$$

where d_{WSN} is the distance between two nodes and $L_p(d_0)$ is the path loss at the reference distance d_0. For all multihop calculations, the coefficients are taken from [8] (Tampere, Finland, district Hervanta). The following comparison assumes the two propagation models and additive white Gaussian noise (AWGN).

TABLE I
SIMULATION PARAMETERS

network topology	BoT	WSN
height TX h_{TX}	$1.5\,\mathrm{m}$	$1.5\,\mathrm{m}$
height MRX and RX	$30/140\,\mathrm{m}$	$1.5\,\mathrm{m}$
power consumption TX	$99\,\mathrm{mW}$	$P_{TX} \cdot \eta_{TX}$
power consumption RX P_{RX}	-	$69\,\mathrm{mW}$
E_b/N_0	$3\,\mathrm{dB}$	$15\,\mathrm{dB}$
noise figure	$5\,\mathrm{dB}$	$10\,\mathrm{dB}$
output Power P_{TX}	$10\,\mathrm{dBm}$	$variable$
G_{RX} and G_{TX}	1	1
η_{TX}	0.1	0.1
datarate r	$variable$	$1.2\,\mathrm{kbit/s}$ or $50\,\mathrm{kbit/s}$

IV. Performance comparison of BoT and IoT

The BoT concept assumes a high performance receiver (MRX) that is operating closely to the theoretical limits, resulting in an $E_b/N_0 = 3\,\mathrm{dB}$. The theoretical lower bound for E_b/N_0 is app. $1.5\,\mathrm{dB}$, by a packet error rate of $P_E = 10^{-4}$, a spectral efficiency $\Gamma = 1/2$ and packet length of $k = 100\,\mathrm{bit}$ [4]. For real implementations an additional margin of $1.5\,\mathrm{dB}$ is assumed. The path loss for the BoT concept is given by equation (2). With the values from table I with $h_{bs} = 30\,\mathrm{m}$ and the environment type small and medium city, a distance of approx. $6\,\mathrm{km}$ in the $868\,\mathrm{MHz}$ band can be reached. So a single MRX can cover a area of approx. $113\,\mathrm{km}^2$.

To get proper values for the multihop WSN communication, the technical data of a state-of-the-art transceiver from Texas Instruments CC1200 [7] is used. The WSN is assumed as a linear multihop network with equidistant spacings between the nodes as in [10], [11] with the path loss model from (3). Using the values from table I and the parameters of the CC1200, the obtained link budget is $133\,\mathrm{dB}$ ($f_c = 868\,\mathrm{MHz}$, $1.2\,\mathrm{kbit/s}$). This results in a maximum range of approx. $750\,\mathrm{m}$ for a node to node communication. For the simulation, the number of hops is adapted to the maximum range, so that for a certain distance d the number of hops n is minimal (visible by the steps in figure 2). In addition P_{TX} is adapted to the minimum required power to reach the neighboring node. The energy to transmit one package E_p with k bits from the source to the sink over n hops by a datarate r can be calculated along:

$$E_p = n \cdot E_{TX} + (n-1) \cdot P_{RX} \cdot \frac{1}{r} \cdot k \quad (4)$$

The power required for the WSN synchronization is not taken into account. Instead perfect synchronization is assumed that leads to more optimistic results for the WSN.

The parameters for the simulation are listed in table I, where the BoT approach assumes two different heights of the MRX. The height of $h_{bs} = 30\,\mathrm{m}$ is a typical height of a tower used in in cellular networks, the $h_{bs} = 140\,\mathrm{m}$ is the height of a power plant chimney in Erlangen, which

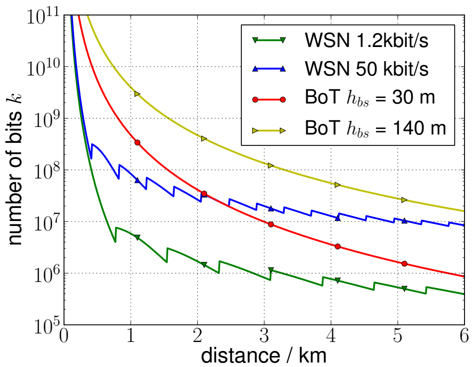

Fig. 2. simulation results: possible transmitted bits k with the energy of a single coin cell for BoT and a multihop WSN

will be used for a future field-trial. Figure 2 compares the BoT concept and a WSN, and shows the overall number of bits that can be transmitted over the given distance d using the energy stored on a $3\,\mathrm{V}$, $30\,\mathrm{mAh}$ coin cell battery. As demonstrated in figure 2, the BoT approach offers a higher efficiency than a multihop WSN, for short to medium distances. The efficiency of the WSN depends on the datarate, two exemplary datarates are illustrated in figure 2. Using a low one of $1.2\,\mathrm{kbit/s}$ the WSN needs 8 hops to reach a distance of $6\,\mathrm{km}$. In contrast, a higher rate of $50\,\mathrm{kbit/s}$ already needs 15 hops to reach the $6\,\mathrm{km}$ target. For small distances up to $500\,\mathrm{m}$, the number of bits for the WSN decreases very fast. This is caused by the higher path loss between RX and TX, but with increasing number of hops the graphs flatten down, due to more efficient transmission. Differing from [10], [11] this paper is based on empirical path loss models and parameters from our coming field-trial.

V. Hardware Demonstrator

The department of Information Technologies of University Erlangen developed a miniaturized TX node (figure 3) to proof the proposed concept. The node is able to transmit 1,000,000 packets ($k = 100\,\mathrm{bit}$, $h_{bs} = 140\,\mathrm{m}$) over a distance of $3.3\,\mathrm{km}$ without changing the battery. The miniaturization naturally requires the implementation of further technologies for improving the performance, e.g. packet splitting [4] and efficient power supply concepts. The HW demonstrator will be used for a field-test to proof the performance of the BoT concept.

VI. Summary and Future Work

This paper introduces the concept of Broadcast of Things (BoT). It shows certain similarities and differences to Wireless Sensor Networks (WSN) and Internet of Things. The range calculation of BoT shows that only one receiver is often sufficient for covering the area of

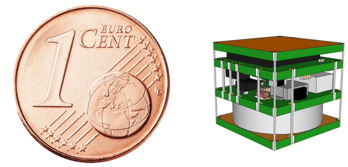

Fig. 3. Hardware demonstrator $1\,\mathrm{cm}^3$ cube with coin cell, power supply circuit, micro-controller, RF-Chip and antenna compared to a 1 cent coin [www.ecb.int]

a complete medium-size city. The comparison between the BoT and WSN shows, that under realistic propagation conditions the BoT concept outperforms WSN, for short and mid ranges. In order to demonstrate the concept of BoT, a TX node was built with a total volume of $1\,\mathrm{cm}^3$. Additional results are expected from a field-trial that uses a receiver in a height of $140\,\mathrm{m}$.

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