Analytical power model for active RFID tag

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Abstract: The RFID system consists of a reader and a large numbers of small, low-cost tags with unique IDs. The active RFID tags are continually powered by batteries and can be read from a greater distance than passive tags. The most critical resource in active tag is battery energy. In this paper we analyze the power consumption of active tag in Real Time Location Tracking (RTLT) system. We show that the distributed MAC protocols are not good candidate.
Keywords: RFID, media access control, power

1. Introduction

The intelligent electronic devices residing in our everyday environment are increasing all the time, which are utilized more than ever in smaller appliances inside our homes and in other environments. Wireless communication between these smart objects and hand-held user terminals facilitates easier interaction between humans and the environment. These applications fall into a category of systems referred to as Ubiquitous Computing System. The wireless communication in Ubiquitous Computing can be based on existing technologies like IEEE 802.11 wireless LAN, Bluetooth or IrDA. However, a problem with these is their remarkably high power consumption. For many smart objects, power supply through the mains is expensive or not at all possible. On the other hand, recharging or replacing the batteries weekly or even monthly is often difficult or impossible, which especially concerns fixed installations and huge number of the devices. Instead, the power supply must be based on energy scavenging or a small battery lasting several months or even years.

Radio Frequency IDentification (RFID) is one of the enable techniques for Ubiquitous Computing [1]. RFID systems consist of RFID tags, or transponders, and RFID readers, or transceivers. Tag readers interrogate tags for their contents by broadcasting a radio signal. Tags respond by transmitting back resident data, which is typically a unique serial number. RFID tags have several major advantages over optical barcode systems concerning the reading distance and speed. Tag data may be read automatically without line of sight, through non-conducting materials such as paper or cardboard, at a rate of several hundred tags per second, and from a range of several meters. Since tags typically are a silicon-based microchip, functionalities which range from integrated sensors, to read/write storage, to supporting encryption and access control beyond simple identification may be incorporated into the design. RFID tag can be either powered actively or passively, which is termed passive tag, battery assistant tag and active tag respectively. Active tag uses an internal battery to continuously power both the logical circuit and the RF communication circuitry of the tag, whereas passive tag totally relies on RF energy transferred from the reader to power the tag. The battery assistant tag falls between them where the battery only powers the RF communication circuitry.

In this paper, we present a power analysis of active tag in real time positioning system. Section 2 gives a brief introduction to RFID system components, describes the interface between tags and readers, and presents estimates of the capacities of current low-cost tags. Section 3 and section 4 present a power model to analyze the power consumption of active RFID tag with typical media access protocol. In section 5, we give a discussion of the unique features of RFID network and the impact on multiple access control. Finally, we summarize in section 6.

2. RFID system primer

Everyday object physically labeled with a tag can identified in an RFID system. RFID systems are composed of three key elements:

- RFID tag, carries object identifying data.
- RFID reader, reads and writes tag data.
- back-end database associates records with tag data collected by readers.

RFID tags typically are composed of a microchip for storage and performing logical operations, and a coupling element, such as an antenna coil, used for wireless communications. Memory on tags may be read-only, write-once read-many, or fully rewritable. Tag readers interrogate tags for their contents through an RF interface. As well as an RF interface to the tags, readers may contain internal storage, processing power, or an interface to back-end databases to provide additional functionality. Tags may either be actively or passively powered. Active tags contain an on-board power source, such as a battery, while passive tags must be inductively powered via an RF signal from the reader. The distance between reader and is limited by the tag's power. Consequently, active tags can be read from a greater distance than passive tags. While passive tags can only operate in the presence of a reader and are inactive otherwise, active tags may record sensor readings or perform some computation in the absence of a reader. This enables communication after signal processing, which can greatly reduce traffic load. The active RFID and passive RFID address different but often complementary issues. Because of long distance with security and large data storage, active RFID is best suited in dynamic movement, sophisticate security, sensing and data storage environment which need continuous movement monitor and long distance communication, e.g. Real Time Location Tracking (RTLT) of assets and personal and sensor monitoring. On the contrary, passive RFID is a better choice for local area and slow movement application, e.g., toll gate, access control and ID identification.

Most manufacturing processes currently deploying RFID systems are for higher value items, allowing tag costs to be in the US$0.50-US$1.00 range. To achieve significant market penetration, the expected price of RF tags is in range of US$0.05-US$0.10 [2]. This price range places the burden of media access control, security and power consumption of tags since the tag must be extremely simple.

Readers must be able to address a particular tag from among a population of many tags. The anti-collision algorithms can either be probabilistic or deterministic [1]. In deterministic algorithm like binary tree-walking scheme, the reader queries all nearby tags for the next bit of their ID number. On occurring a collision, there are at least two tags among the population have different bit values in that position of the ID. The reader then send a response bit to split tags into two groups, one group of tags should continue with the protocol and another group of tags should cease responding. Each choice of bit represents choosing a branch in a binary tree. The leaves of the tree correspond to tag ID numbers. Benefits of binary tree-walking include simple tag implementation and efficiently broadcasting only the bits of an ID to singulate any tag. Thus, it is mainly used by passive tag. A familiar probabilistic algorithm is ALOHA scheme which is mainly adopted by active RFID system. The tags avoid collisions with other tags by responding to reader queries at random intervals. Higher densities of tags will result in a higher collision rate and degraded performance.

3. Media access control of active RFID network

In active RFID tag, the most critical resource is power [3]. Tags are in Sleep state where the radio circuits are shut down and only watch-dog circuit work to save battery power. In RTLT system, tags usually work in Tag-Talk-First mode, where tags enter active state from sleep state periodically and blink tag ID number spontaneously [4]. Tag position can be therefore determined by triangulating signal strength or time of arrival. This is different from the active tag for asset tracking.

There are two simple ways for tags to contend the reader, pure ALOHA and non-persistent Carrier Sense Multiple Access (CSMA). In pure ALOHA way, tags in active state simply blink without any consideration on the channel condition. The tag can be as simple as transmitter only, e.g. Spider tag from RFCODE [5]. The problem of pure ALOHA is the high packet collision probability in the case of high density of node distribution. In non-Persistent CSMA way, tags in active state sense the channel before transmission. The blink is retracted in the case of a busy channel. The pros of pure ALOHA is its simplicity and cheap price.

4. Power model of active RFID network

In this section, we assume that all transmitter-only tags blink with the same configuration and are independent of each other. We also assume that the channel is free of noise. And, any blink collision results in an error read.

The state of active can be generally described as three states: Transmission, Receive and Sleep. The tag ID is sent in Transmission state; the optional Receive state is to sense the channel state and receive command from reader; while in Sleep state all the circuit except watchdog is shut down.

Consider a RFID system with a reader and *N* active tags. As shown in Fig. 1, the average blink interval is *ß*, and the blink size is T_0. The total power consumption of a tag in a blink, P_a, can be computed as

$$\begin{aligned} P_a &= P_{tx} + P_{rv} + P_s \\ &= C_{tx}T_0 + C_{rv}T_{rv} + C_s(\beta - T_0 - T_s - T_{rv}) \end{aligned} . \quad (1)$$

where C_{tx}, C_{rv} and C_s are power consumption in Transmission, Receive and Sleep state, respectively. Given a battery capacity *B*, the lifetime of a tag becomes

$$L = B\beta / P_a . \quad (2)$$

The interval between two neighbouring blinks can be defined by an exponential random variable *t*, where $p(t)=\frac{1}{\beta}e^{-t/\beta}$. The virtual offered load can be given by $G=\frac{NT_0}{\beta}$.

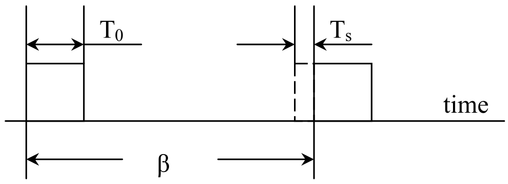

Fig. 1 timing of tag blinks

4.1 Power in pure ALOHA

We can define a collision window of size $2T_0$. In a blink cycle, the probability of none of $N\text{-}1$ blinks colliding with the ongoing blink is

$$p_c(N)=e^{-2T_0(N-1)/\beta}. \tag{3}$$

The average good blink interval is $\frac{\beta}{p_c(N)}$. Since no channel condition is considered in pure ALOHA access, the power consumption during a blink period is

$$C_A=C_{tx}T_0+C_s(\beta-T_0). \tag{4}$$

The power consumption for a good blink is

$$P_A=\frac{1}{C_A p_c(N)}. \tag{5}$$

4.2 non-Persistent CSMA

The pure ALOHA may spend unnecessary power on packet collision. CSMA reduces the incidence of collision by channel sensing before packet transmission. The throughput can be given by [6]

$$S_c=\frac{Ge^{-aG}}{G(1+2a)+e^{-aG}}, \tag{6}$$

where a is the one-way propagation delay. To get a successful blink, a tag must blink (including both transmissions and withdraws)

$$\overline{N_{cb}}=\frac{G}{S_c}=\frac{G(1+2a)+e^{-aG}}{e^{-aG}} \tag{7}$$

times. In a blink period, the probability of blink transmission can be given by

$$p_t=\frac{aG+1}{G(1+2a)+e^{-aG}}. \tag{8}$$

Thus, the average current consumption in a blink period becomes

$$C_C=C_{tx}p_tT_0+C_{rv}T_s+C_s(\beta-T_0-T_s). \tag{9}$$

where T_s is the size of channel sensing window. The power spends on a good blink is

$$P_C=C_C\overline{N_{cb}} \tag{10}$$

4.3 non-Persistence CSMA with hidden node

However, the non-Persistent CSMA suffers from hidden node problem where two tags are out of range of each other or if they are separated by some physical obstacle opaque to RF signal. For example, as shown in Fig. 2, a typical radio range of Spider tag is 100 meters in office environment. Assuming that sensing range of tag is the same as radio range. When all tags uniformly distribute in a square area whose side is 140 meters, the average probability of distance between two tags is greater than 100 meters is 24.86%. This is the probability of hidden node, which becomes even large when we consider the real radio signal can propagate in 3D space.

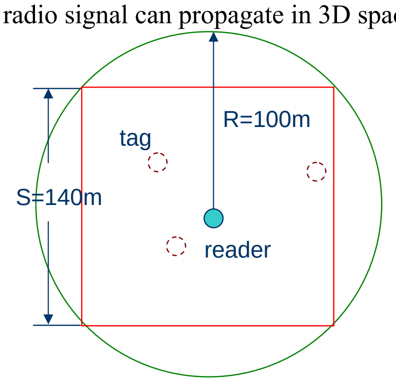

Fig. 2 Radio range and considered area of CSMA

For simplicity, we divide the total tag set into two groups: sensed group and hidden group [7]. A tag can hear all the others tags in its group. In the same group, the channel is shared as non-persistence CSMA. The hidden group contend the channel with sensed group in pure ALOHA way.

Assume there are γN tags in the hidden group, the offered load in sensed group is

$$G_s=(1-\gamma)G \tag{11}$$

and the offered traffic in hidden group is

$$G_h=\gamma G \tag{12}$$

We consider a tagged blink from sensed group. A tagged blink from the sensed group is not corrupted by packet from hidden group, two conditions must be satisfied [7]:

1) tagged blink does not occurs during any transmission period of hidden group
2) no blink from hidden group occurs during the transmission period of tagged packet

In the hidden group, the average busy period is

$$\overline{B_h} = 1 + 2a - \frac{(1 - e^{-aG_h})}{G_h} \qquad (13)$$

and the average idle period is

$$\overline{I_h} = 1/G_h \qquad (14)$$

In the first condition, a tagged blink occur during the last a second of transmission period of hidden group is $\frac{a}{\overline{I_h} + \overline{B_h}}$. The probability is therefore

$$p_1 = \frac{e^{-G_h(1-a)} - e^{-G_h}}{G_h(\overline{I_h} + \overline{B_h})}. \qquad (15)$$

The second condition is the probability of the tagged blink occurred during idle period and no blink from hidden group occurs

$$p_2 = \frac{\overline{I_h} e^{-G_h}}{\overline{I_h} + \overline{B_h}}. \qquad (16)$$

The throughput of the sensed group can be given as

$$S_{ch\_s} = \frac{G_s e^{-aG_s}}{G_s(1+2a) + e^{-aG_s}}(p_1 + p_2). \qquad (17)$$

In the sensed group, the blink transmission probability is

$$p_{ch\_st} = \frac{a + 1/G_s}{\overline{B_s} + \overline{I_s}}(1-\gamma) + \frac{a + 1/G_h}{\overline{B_h} + \overline{I_h}}\gamma, \qquad (18)$$

where $\overline{I_s}$ and $\overline{B_s}$ are idle period and busy period of sensed group, respectively.

4.4 Power analysis

In this section, we show result of the above analysis. The current consumption of RF transceiver is based on CC1000 from CHIPCOM [8]. The packet size and data rate refer to ISO/IEC 18000-7 and we set packet duration to 3.4 milliseconds [9]. The propagation delay and channel sensing window is 1‰ of the packet duration. The detail values are listed in Table 1. Consider the case in which there are 800 tags in the radio range of a reader. Tags uniformly distributes in a space described in Fig. 2.

Table 1 Compute parameters

Tag set		800
Battery capacity		220 mAh
Tag blink	Blink duration	3.4 ms
	Blink interval	0.3s ~ 1000s
	Delay	3.4 µs
Channel sense window		3.4 µs
Current	Standby (digital and RF part)	4 µA
	Blink transmission	15 mA
	Blink receiving	10 mA

Figure 3 shows the power consumption per good blink for pure ALOHA and non-p CSMA in which we assume the probability of hidden node is 20%. We average the case of tag in sensed group and hidden group. The non-p CSMA outperforms pure ALOHA when tag blink interval is very short, which means a heavy network load. When network is slightly loaded, G<0.05, there are almost no difference between the two methods. Figure 4 gives the expected lifetime of the active tag. In the case of a heavy load network, the expected lifetime is about 2 times as that of pure ALOHA. When we consider a narrow space where all the tag can hear each other, the lifetime of tag is almost doubled. This mean the hidden node is one of the key in issue in design a long lifetime tag. The popular Request-To-Send (RTS) and Clear-To-Send (CTS) does not work. These commands may even larger than the short tag ID and give too much control loads.

In Fig. 5, we show the power consumption distribution between blink transmission, channel sensing, receiving and standby in non-p CSMA system. We set the tag must wakeup every another blink interval to receive command from the reader. This is defined as event blink and exciter blink in US standard of RTLT system [4]. In a heavy load network, blink transmission and receiving dominate the power budget. With increment in blink interval, tag standby power increase monotonously. The transmission power budget increase to its peak and decrease after that. The peak area is the best network load for since the RTLT system since most part of power is used to locate the objects, which is 0.03<G<1. The high transmission power in heavy load case is because of the hidden node. Also, we find that the power spending on receiving cannot be ignored in the suitable area. How to reduce the receiving power is another key issue.

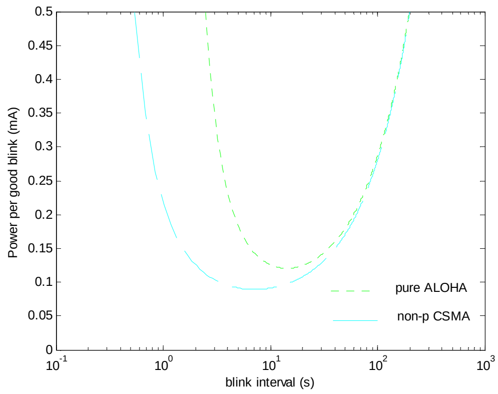

Fig. 3 Power consumption per good blink

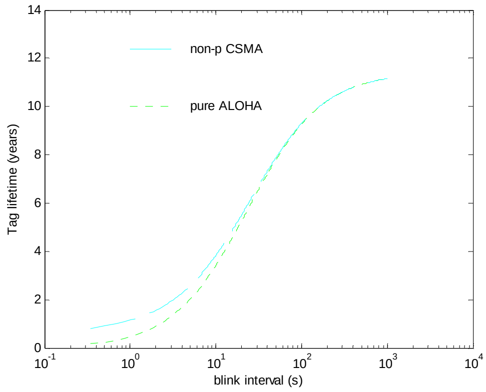

Fig. 4 Expected tag lifetime

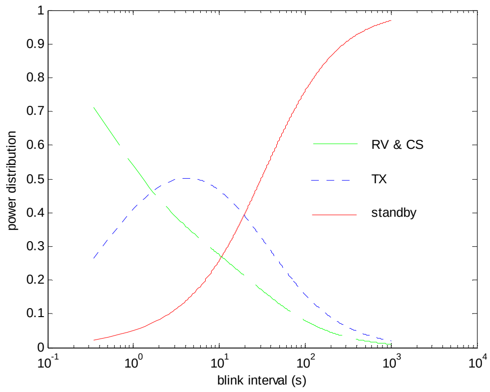

Fig. 5 Power consumption distribution in non-p CSMA system

5. Analysis on RFID network MAC

Due to the target application and market, a RFID network is organized into centralization architecture, rather than distributed peer-peer architecture. The communication occurs only between reader and tag. There is not direct communicates between tags. The contention only occur when tag initiate the communication. Furthermore, there is no real time multimedia traffic over RFID network. The dominant traffic is short burst tag ID. However, the pure ALOHA and non-persistent CSMA are both distributed network protocols.

A prominent feature of RFID network is asymmetric. From device aspect, while RF tags must be small, simple, cheap, there are almost no these requirements to reader. The readers are not necessary portable devices and can be pretty expensive. From resource aspect, RF tags are serious lack of energy budget and computing ability. Usually, readers are equipped with enough power and strong computing ability. That is only RF tags work in resource scarce environment. From distribution aspect, the number of readers in an area is limit and their distribution is sparse. On the contrary, RF tags can cluster around a reader in very high density. The traffic between tag and reader is asymmetric, too. In general, there are simple commands in downlink from reader to tags. As a contrast, a large amount of data, (tag IDs and sensed data), congest the uplink from tag to reader. It is important for the MAC protocol to use the asymmetric characteristics.

6 conclusions

In conclusion, we analyze power consumption of active RFID tag for RTLT system. Two simple MAC protocol, pure ALOHA and non-persistent CSMA are analyzed. In order to get a long lifetime tag, to reduce the power on receiving and blink transmission is important. We show that the distributed MAC protocols are not good candidate.

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