

# Bluetooth/802.11 Protocol Adaptation for RFID Tags

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## ABSTRACT

*The 2.4 GHz frequency band is available throughout most parts of the world for low cost short-range wireless communications and has increased in popularity with the proliferation of networking and cordless technologies based on IEEE 802.11 and Bluetooth. A growing number of RFID systems have also been designed for operation within the 2.4 GHz ISM frequency bands. As more wireless technologies sought to use the 2.4 GHz band, co-existence and protocol compatibility issues have become even more pronounced. We characterize the expected performance of power efficient, protocol compatible backscatter-based RFID tags in the ISM band. We also propose an architecture for a hybrid backscatter-based RFID tag that can co-exist in an 802.11 or Bluetooth infrastructure while greatly improving its battery life.*

## 1 INTRODUCTION

The automatic identification and data capture (AIDC) industry has recently begun to aggressively evaluate active RFID tags for applications now requiring enhanced security and improved efficiency for tracking and locating high-value assets in real-time. Emerging high performance active tag products operate within the 2.4 GHz ISM band while their passive counterparts have been proposed for operation within disjointed UHF bands that have not yet been harmonized across the world. Nevertheless, we do expect that eventually, most high performance passive RFID tag technologies will operate in the UHF frequencies from 862 MHz to 928 MHz across Europe and North America [1]. Conversely, we also expect that active tag technologies will seek to become protocol compatible with low cost communication system standards that currently operate within the worldwide unlicensed 2.45 GHz Industrial, Scientific, and Medical (ISM) band. Doing so leverages design synergies with other ISM band products such as Bluetooth and IEEE 802.11, provides infrastructure added value, and reduces overall deployment costs. We summarize the *main* advantages and disadvantages of operation within the UHF and microwave frequency bands as follows:

### UHF (862 MHz to 928 MHz)

#### Main Advantages

- Best range and throughput for both passive and battery powered backscatter-based (semi-passive) RFID tags [1][2].
- Significantly fewer *co-located* technologies that will compete for channel access and generate

interference (although cell phones do operate in nearby frequency bands and may generate some interference under certain circumstances.)

#### Main Disadvantage

- Frequency bands are not harmonized for worldwide operation.

### Microwave (2.4 GHz ISM)

#### Main Advantage

- Frequency band is available throughout most parts of the world. Although the maximum allowed transmitted power levels currently vary widely, we expect greater uniformity as manufacturers begin worldwide deployment of consumer products based on 802.11 and Bluetooth technologies.

#### Main Disadvantages

- Greatly reduced range and throughput for both passive and semi-passive RFID tags.
- Must co-exist with numerous other ISM band technologies. Channel or bandwidth sharing will further reduce throughput.

In Section 2, we show that semi-passive UHF RFID tags provide several orders of magnitude improvement in interrogation distance (per unit of antenna area) over similar products operating in the microwave frequency band [1]. We also show that for the same operating distance, we can achieve higher effective data rates within UHF bands as well as reduce the energy requirement per unit of information transmitted. However, we do not expect worldwide harmonization of the UHF frequency bands in the near future. Therefore, we propose the concept of 802.11 and Bluetooth protocol compatible tags in Section 3 to address the ISM band co-existence issue.

## 2 RANGE AND DATA RATE

### 2.1 Backscatter Radiation

When passive and active tags transmit a signal via backscatter radiation, they modulate their antenna impedance in synchronization with a transmitted bit stream to reflect continuous wave (CW) energy from the base station or interrogator. That is, backscatter based RFID tags do not independently radiate energy through power conversion from their local energy source. Backscatter radiation results in low modulation index, amplitude modulated (AM) signaling at the interrogator. The rate or phase of this AM signal modulation typically encodes transmitted data on a

frequency modulated (FM) or phase modulated (PM) sub-carrier respectively.

When reflecting a CW signal, the tag antenna characteristics are modified so that it becomes mostly a *poor collector* of RF energy. For example, shorting the two terminals of a dipole or switching in an extra capacitor or inductor tap is a simple way of configuring the antenna as a poor collector or *reflector*. This has the effect of changing the antenna radiation efficiency, which in turn results in a change of its gain and matching efficiency.

For battery powered tags utilizing backscatter radiation rather than active transmission (semi-passive tags), we expect that the signal received by the base station will experience typical multi-path fading. We calculate the maximum data rate ( $R_{bit}$ ) possible with non-coherent ASK demodulation of backscatter radiated signals from [2],

$$R_{bit}(r, p_e) = P_s \Psi_T^2 \Psi_r \left( \frac{\lambda}{4\pi r} \right)^4 \times \frac{1}{\left(1 + r/R_0\right)^{2(N_B-2)}} \left( \frac{1}{k_B T_0 f_r} \right) \frac{1}{2 \ln \left( \frac{1}{2p_e} \right)} \quad \text{Eq. 1}$$

Table 1 summarizes the parameters of Eq. 1 and their values based on a typical backscatter RFID system design.

Table 1: Parameters for calculating the range and throughput of semi-passive tags.

	Value	Units	Definition
$P_s$	100	Milli-Watts	CW power radiated by the interrogator.
$\lambda$		Meters	Wavelength of the RF carrier.
$\Psi_T$	1.475		The base station transmitter antenna realized gain.
$\Psi_r$	1.426		The backscatter antenna reflectivity factor.
$R_0$	4	Meters	Breakpoint distance when free-space path loss transitions to a higher loss index.
$N_B$	4		Multi-path propagation loss index typically observed in a cluttered warehouse.
$p_e$	$10^{-6}$		Maximum acceptable probability of bit error (BER.)
$T_0$	298	Degrees Kelvin	Reference temperature for noise factor.
$k_B$	$1.38 \times 10^{-23}$	Joules/Kelvin	Boltzman's constant.
$f_r$	100		Receiver noise factor (derived from its noise figure specified in dBs.)

We can intuitively interpret this expression as follows:

- Bit-rate ( $R_{bit}$ ) is *linearly* proportional to realized or net power gain of both the transmitting ( $\Psi_T$ ) and reflecting ( $\Psi_r$ ) antenna systems.
- Bit-rate is inversely proportional to the signal propagation losses at a given distance based on the channel propagation ( $R_0, N_B$ ) characteristics.
- Given a maximum desirable bit error probability ( $p_e$ ), the bit rate is inversely proportional to the base station receiver noise factor ( $f_r$ ) or equivalently its

noise figure. Hence we can conclude that given no other changes, we can improve the bit rate or throughput of the communication system by the same factor that we can reduce the receiver noise figure. Therefore, we can achieve higher system throughput ( $R_{bit}$ ) at a given desirable maximum operating distance  $r$ , maximum regulated output power ( $P_s$ ), minimum realizable antenna system gain ( $\Psi_T \Psi_r$ ), and the maximum desirable bit error rate ( $p_e$ ) simply by reducing the receiver noise figure ( $f_r$ ). However, reducing a receiver's noise figure does come at the expense of higher burst power consumption. Likewise, we must also increase the base station receiver bandwidth in order to accommodate the higher modulation speed without degrading its noise figure. Doing so also implies increasing the receiver power consumption.

- The maximum possible bit rate for a given communications distance  $r$  improves with the fourth power of the carrier wavelength  $\lambda$ . The implication here is that given the greater signal collection capability of antennas at lower frequencies, and barring interference, *we can use more bandwidth in order to increase data rate without sacrificing bit error rate*. Unfortunately, greater bandwidth is not always available within the lower frequency UHF bands, for example, compared with higher frequency microwave bands.

Given the same amount of information to transmit, an improvement in bit rate results in shorter packet transmission times. This means that the tag will access the airwaves less often and for shorter time slots. Additionally, shorter packets are statistically less susceptible to interference from other equipment utilizing the same frequency band, therefore resulting in fewer collisions and correspondingly, fewer requests for re-transmission. Hence, higher bit rates will result in a decrease in the *average* power consumption of the tag per information unit communicated since its transceiver will tend to utilize the airwaves less often.

## 2.2 Semi-Passive Backscatter Performance

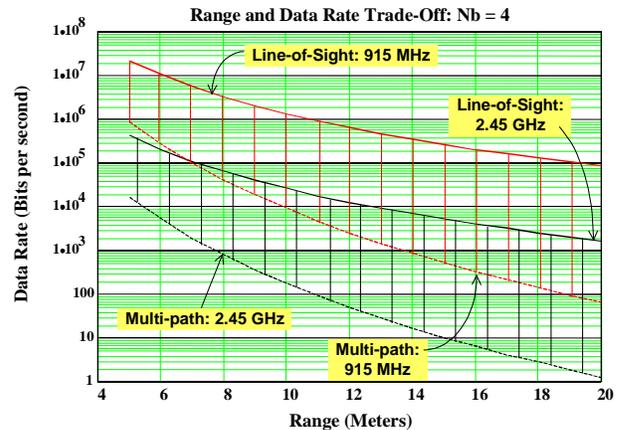


Figure 1: Backscatter range and data rate trade-off in free-space and multi-path conditions.

Given tag interrogators operating under reduced power transmission levels of 100 mW, which is identical to

that of most 802.11 wireless LAN systems, we calculate the range and data rates for typical backscatter based semi-passive tags from Eq. 1. The results in Figure 1 show that within the 915 MHz UHF frequency band, and at a distance of about 10 meters from the base station, data rates between 10 kilobits and one megabit per second are possible depending on the multi-path conditions and receiver sensitivity. In contrast, data rates between 200 bits per second and 30 kilobits per second are possible at 10 meters when operating in the 2.45 GHz frequency band.

We see that in order to match the data rates of 802.11 and Bluetooth systems, the tags must operate within four meters of the transmitter. This has important implications for Bluetooth or 802.11 compliant RFID tags operating in the backscatter mode within the 2.45 GHz frequency band. For maximum throughput efficiency, these types of tags should be designed with adaptive rate scaling so that neither range nor data rates will be sacrificed when propagation conditions are favorable.

Since better receiver sensitivity and higher SNR is possible with active transmission, we should expect orders of magnitude improvement in the range and throughput over backscatter based systems. However, we give up the low power consumption, and hence long battery life (or smaller, lighter, cheaper battery) characteristics that backscatter radiation would provide. Battery life is generally the most important feature amongst similar capability battery powered RFID tags.

### 3 PROTOCOL COMPATIBLE TAGS

In this section, we propose a hybrid RFID tag design that is *protocol-compatible* with existing IEEE 802.11 and/or Bluetooth standards as well as existing RF-tag standards. We construct Bluetooth and IEEE 802.11 protocol compatible RFID tags by retaining the frame structures and channel access mechanisms but add the capability of backscatter radiation and ASK carrier modulation to the RF front-end. This technique allows us to construct a tag with reasonable performance and lowest energy consumption.

#### 3.1 Architecture

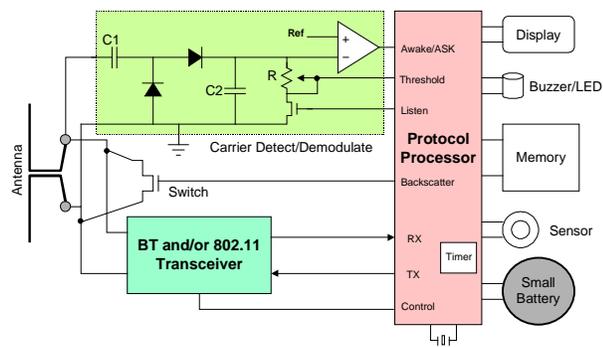


Figure 2: Bluetooth/IEEE802.11b protocol compatible backscatter based RFID tag.

Figure 2 shows the overall proposed architecture of a semi-passive RFID tag that is protocol compatible both with existing RFID tag standards like ANSI-

NCITS:256, and other communication system standards like Bluetooth or IEEE 802.11. Although a different radio front-end is required, this approach allows re-use of the same baseband, protocol, and host interface processor technology currently under development for these standards, without significant additional changes. In the near future, we can expect low-cost, single chip implementations of the 802.11 and Bluetooth standards, and we can utilize such a device as shown in Figure 2.

In order to enhance its power efficiency by a significant amount and hence greatly increase the tag's battery life, a multi-protocol interrogator can switch the tag to a backscatter radiation mode and emit CW energy in a frequency-hopping pattern when receiving a response. The tag may maintain protocol compatibility by switching the antenna impedance in synchronization with a Bluetooth/802.11 frame organized bit stream. For reception, the tag can utilize traditional demodulation techniques via the 802.11/Bluetooth transceiver chip or it can also switch to a more power efficient and simpler ASK demodulation technique.

We also propose a carrier sense circuit that provides an asynchronous wake-up mode, thus providing the tag with a tremendous power savings feature. That is, the tag can be completely powered down when not in use and awakened only when it comes within a pre-determined distance of the interrogator. We can program this distance via setting signal strength thresholds through communications with the processor. The threshold circuit can be implemented as a digital resistor as shown. We also propose combining the carrier sense circuit with ASK demodulation as shown so as to remain compatible with existing and simpler RFID tag protocols that use it. In essence, this design supports multiple existing RFID tag protocols as well as adaptations from non-traditional RFID tag protocols like IEEE 802.11 and/or Bluetooth.

#### 3.2 Protocol Considerations

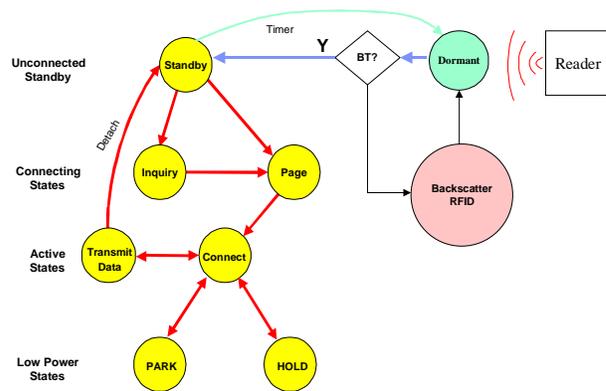


Figure 3: State machine for Bluetooth and traditional RFID protocol compatibility.

Figure 3 illustrates the proposed state transitions from a tag wake up sequence. This flexibility in active transmission or backscatter radiation is useful in that any Bluetooth enabled device [5] can communicate with the hybrid tag, as well any traditional RFID

interrogator. The tag will determine which mode to utilize by examining the interrogator signal transmission characteristics and organization of the header sequence. Once awakened by the presence of a pre-determined intensity RF signal from the interrogator, the tag leaves its lowest power consumption state and determines whether Bluetooth, for example, or traditional RFID protocol communications is required. The tag does so by examining the validity of the presently received frames from both the Bluetooth and ASK demodulators. If traditional RFID communications is required, the tag will temporarily shut down the Bluetooth transceiver before proceeding with normal backscatter based RFID communications. Otherwise, standard Bluetooth communications may commence in either the backscatter radiation or active transmission mode.

Backscatter based RFID interrogators are unique with respect to their ability to co-exist in a multi-user and multi-mode wireless communications channel. For example, backscatter RFID tags cannot send unsolicited messages unless the interrogator first establishes a CW RF field that can be reflected to its receiver. Therefore, a multi-mode RFID interrogator may negotiate with other communications devices in the area for collision free time-slots. It may do so either through a common wired network connection to other access points (APs) or by emulating their RF signaling formats. For example, when the interrogator is ready to read RFID tags, it may issue a request-to-send (RTS) command to the nearby 802.11 AP or mobile device. Figure 4 shows the general organization of an 802.11 RTS frame [4].

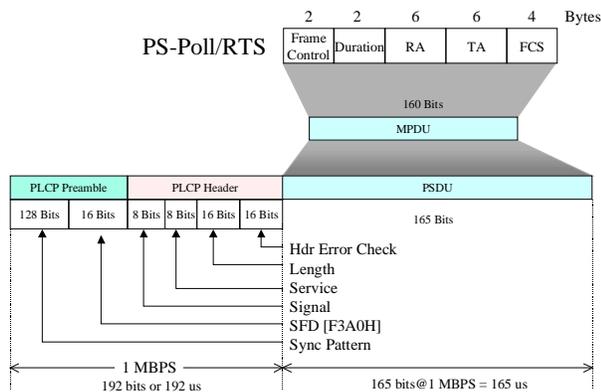


Figure 4: Organization of an 802.11b RTS or PS-Poll frame.

Once the interrogator receives a clear-to-send (CTS) response, all other 802.11 devices will refrain from using the channel per the requested time-slot reservation period by setting the appropriate time-out on their network allocation vector (NAV) timer. The interrogator then commands the RFID tag for the communications mode that suits it best. For example, it may request that the RFID tag communicate via backscatter radiation using a simpler RFID communications frame format rather than the more complex 802.11 frame format so as to reduce power consumption. This architecture also works with

any of the IEEE 802.15 TG2 [3] proposals for co-existence within the popular ISM bands.

#### 4 SUMMARY AND CONCLUSIONS

In summary, we listed the key advantages and disadvantages of RFID tags that operate within the UHF and microwave ISM bands. We showed that even though UHF band RFID tags operate with higher range and data throughput, the fragmentation of allocated UHF frequency bands across the world currently hampers their successful deployment. On the other hand, while not as limited by frequency harmonization issues, we showed that microwave-based semi-passive RFID tags can still provide reasonable performance for most asset-tracking applications. However, their application within the popular 2.4 GHz ISM band will be limited by co-existence issues as other popular wireless network and cordless technologies such as 802.11b and Bluetooth proliferate. We, therefore, propose a concept and architecture for a protocol compatible hybrid Bluetooth/802.11 RFID tag.

#### 5 REFERENCES

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- [5] Bluetooth Specification 1.1.

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