Low Power RF Receiver Requirements of Wireless Sensor Network for Coexistence with Various Wireless Devices in 2.4GHz ISM-band

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Abstract

This paper describes the analysis for implementation of a radio frequency (RF) receiver for low-rate wireless personal area networks (LR-WPANs), namely IEEE 802.15.4, for coexistence with various wireless devices in 2.4GHz ISM-band. With IEEE 802.15.4 standard specification, it provides analysis of receiver performance require-ments containing the system noise figure (NF), system third-order intercept point (IIP_3), local oscillator phase noise and selectivity. With some assumption, it illustrates relation-ship between minimum detectable signal (MDS) and various situations considering for the effects of noise generated from other wireless devices according to communication distance. Here, we can infer the necessity of much tighter specification requirements than standard's that for various communication field environments.

1. INTRODUCTION

Wireless sensor networks are an emerging research area with potential applications in environmental monitoring, surveillance, military, health and security. Such a network consists of a group of nodes, called sensor nodes, each with one or more sensors, an embedded processor, and a low power radio. Typically, these nodes are linked by a wireless medium to perform distributed sensing tasks [1].

In recent years, the concept of a standardized low rate wireless personnel area network (LR-WPANs) has appeared. Fuelled by the need to enable inexpensive wireless sensor network applications, in December 2000 Task Group 4, under the IEEE 802 Working Group 15, were formed to begin the development of a LR-WPAN standard IEEE 802.15.4. The goal of Task Group 4 is to provide a standard that has the characteristics of ultra-low complexity, low-cost and extremely low power for wireless connectivity [2-3].

The system performance of major specification items required at the standard of IEEE 802.15.4 physical layer is much degraded because of various interferers generated in wireless devices in ISM-band. So, a specification analysis in this frequency band deliberated on interferers' environment according to distance may be required for the solution of coexistence problems.

Section 2 of this paper presents the analysis and simulation of RF receiver requirements considering for coexistence problems between IEEE 802.15.4 and IEEE 802.11b/802.15.1. Conclusions are presented in Section 3.

2. THE ANALYSIS OF RF RECEIVER REQ-UIREMENTS

2.1 Derivations of RF receiver specification from Standard

The data of LR-WLAN is coded onto the carrier with direct sequence spread spectrum (DSSS), an inherently robust wireless communication technique of improving multipath performance and receiver sensitivity through signal processing gain (PG). This PG decrease minimum SNR demanded from a baseband demodulator for the achievement of desired BER. The SNRmin can be described by (1)

$$SNR_{min} = E_b / N_0 - PG_{despreading} + BB\_margin \quad (1)$$

The PGdespreading can be defined as the ratio of chip rate to data rate and implies spectrum-despreading gain of a baseband demodulator. The Eb/N0 can be defined as the ratio of traffic channel bit energy to noise density. With considering these effects and baseband imple-mentation loss, a baseband demodulator margin (BB_margin) is defined. In this paper, the BB_margin will be assessed by 2dB. The noise figure containing a BB_margin is shown (2)

$$\begin{aligned} NF_{required} &= SNR_{in} - SNR_{out} \\ &= P_{signal} - KTB - (E_b / N_0 - PG + BB\_margin) \end{aligned} \quad (2)$$

The Psignal represents the wanted-signal power injected into antenna, and KTB is thermal noise power considering a bandwidth. For example, when a PG is used along with a data rate of 250kbps, the NFrequired becomes 23dB with a Psignal of –85dBm, KTB of –111dbm, Eb/N0 of 10dB, and BB_margin of 2dB.

Generally, the system-IIP3 can be derived from inter-modulation distortion (IMD) test condition suggested on any standard specification. This performance parameter indicates an extent of the distortion of an RF/analog-path against strong interferers generated by other user. The IEEE Standard for Part 15.4 [4] doesn't suggest interferer's condition, so the assumption of contribution of receiver noise power for LR-WPAN must be fulfilled. The major noise components inducing the SNR-degradation of a receiver are consisted of normal-noise part and distortion-

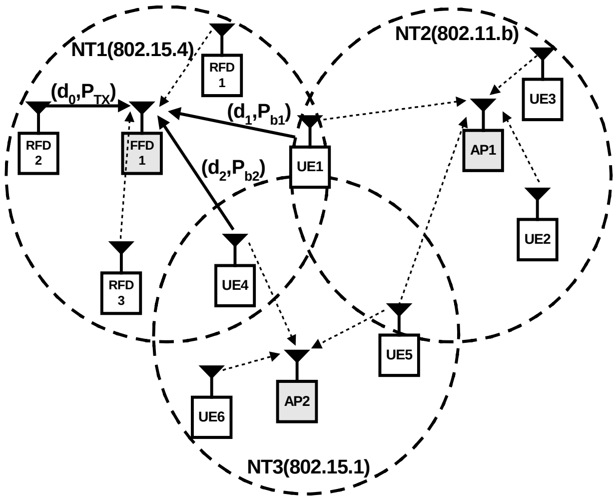

Fig.1 Communication block-diagram of LR-WPAN against interferers generated from various communication systems in 2.4GHz ISM-band.

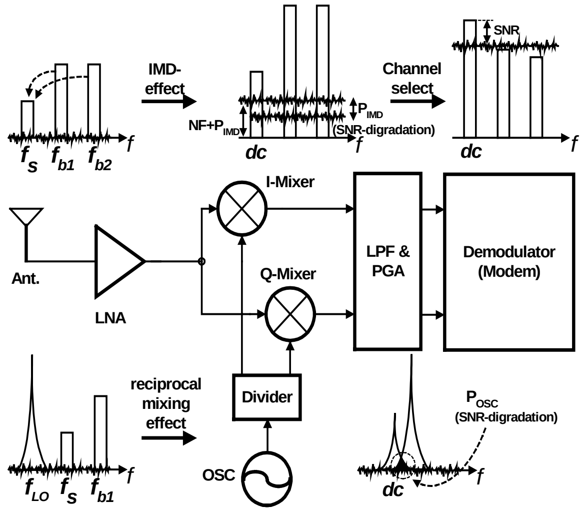

Fig.2 SNR-degradation of a receiver containing IMD and reciprocal mixing effects by interferers.

noise part generated from other systems. The Paccept.noise required from a receiver is shown (3)

$$P_{accept.noise} = P_{normal.noise} + P_{distortion.noise} \\ = P_{signal} - (E_b/N_0 - PG + BB\_margin) \quad (3)$$

The distribution of the Pdistortion.noise is: PCW-blocking, 30 percent of power; PMOD-blocking, 30 percent of power; PIMD, 30 percent of power; and POSC, 10 percent of power as shown in the Ref. [5].

With the Psignal of -82dBm and the SNRmin of +1dB, the PAccept.noise will be accepted by -83dBm, the Pnormal.noise by -86dBm, and the Pdistortion-noise by -86dBm. In this paper, since the PIMD is assumed to 30 percent, the PIMD can be accepted by -91dBm, and the POSC to 10 percent, the POSC by -96dBm. The IIP3 required from a receiver is shown (4)

$$IIP_{3,req} = P_{signal} + 0.5(P_{signal} - P_{IMD}) \quad (4)$$

Assuming the IMD test scenario with the Pblocker of -52dBm, the system-IIP3 is required by -34dBm (@10M/20MHz). The phase noise required from local oscillator (LO) is shown (5)

$$Phasenoise_{LO} = P_{OSC} - P_{signal} - 10\log(BW) \quad (5)$$

Assuming the IMD and blocking test scenario with the Pblocker of -52dBm, the phase noise of LO is required by -87dBc/Hz (@1MHz).

The selectivity of a receiver for in-band and out-of-band rejection will be determined by the attenuation performance of RF/IF/baseband filters. In these specifications, the adjacent-alternate channel rejection (AACR) is defined by relative attenuation of adjacent-channel power and alternate channel power. The selectivity required from a receiver at 5/10MHz-offsets frequency is shown (6)

$$Selectivity(@5MHz) \geq P_{blocker} - P_{accept.noise} \ : adjacent\ CH. \\ Selectivity(@10MHz) \geq P_{blocker} - P_{accept.noise} : alternate\ CH. \quad (6)$$

Assuming the test scenario with the Pblockers of -82/-52dBm, the selectivity is required by +1/31dBc (@ 5/10MHz), respectively.

2.2 RF receiver requirements considering for coexistence

In PHY-layer standard specification of IEEE 802.15.4, the channel selection methods are introduced with channel clear assessment (CCA) and energy detection / link quality indication (ED / LQI). This methods are that don't communicate and wait or move into other channels when exist strong interferers. With these situations, the more appearance of application devices using a 2.4GHz ISM-band will lead the less probability of call-success. So, in this paper, we will extract the proper specification of RF/analog-path of PHY-layer for the probability of call-success against coexistence problems.

Unfortunately, the blocker profiles don't be minutely specified in unlicensed frequency band of 2.4GHz with various wireless communications. Really, the possible strong blockers will considerably degrade performances of RF-receiver system.

So, the system budget, which contains specifications of the performance parameters of a receiver, is required with considering about strong interferers.

The communication block-diagram of LR-WPAN against interferers generated from various communication systems in 2.4GHz ISM-band is shown in Fig.1. In this Fig.1, the receiver of FFD1 does only want to communicate with the transmitter of RFD2. But it does simultaneously receive transmitters' signals from a UE1 and UE4 of NT2-network (IEEE 802.11b) and NT3-network (IEEE 802.15.1), respectively. In this case, the FFD1 receives unwanted blockers' signals: Pb1 and Pb2 according to distance d1 and d2, respectively. In example, with worst-case field environment for very short distance, i.e. one meter, and transmission of allowable maximum power, the sensitivity of receiver is rapidly degraded because of inter-modulation distortion products and reciprocal mixing products generated by strong interferers.

The SNR-degradation of a receiver containing inter-

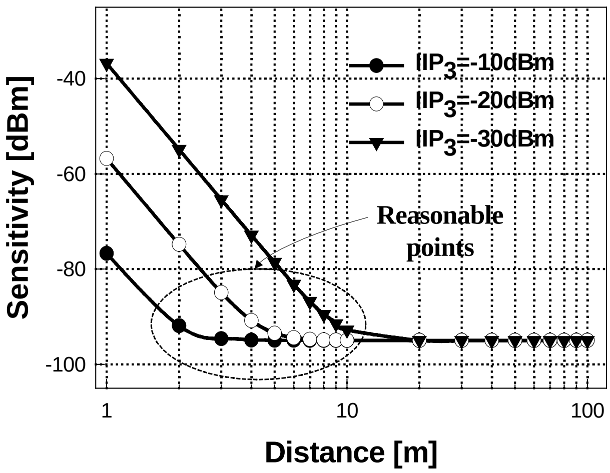

Fig.3 Sensitivity vs. distance according to various system-IIP$_3$

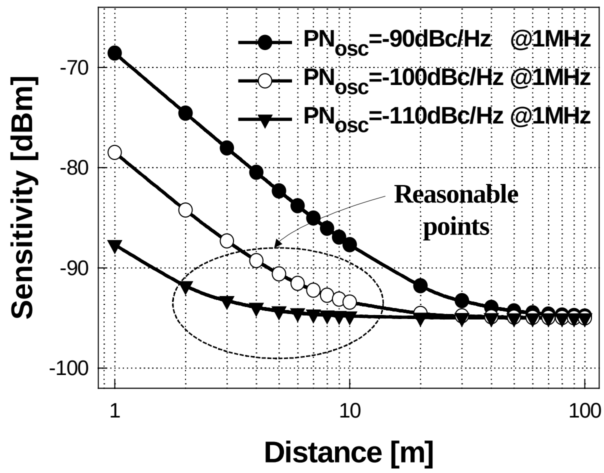

Fig.4 Sensitivity vs. distance according to various LO PN

modulation distortion (IMD) and reciprocal mixing effects by interferers is shown in Fig.2. To reduce the SNR-degradation by strong interferers, there are two solutions. One method is to decrease noise components, which get in a wanted in-channel, by the reduction of interferers' signal power. By using the transmitter's power control algorithm of other communication standard, this method is the most efficient. But, this is not a good solution because of problems beyond our standard category. The other method is to increase requirements of the receiver performance parameters. In this paper, we will calculate the major parameters of receiver performance: system-IIP3, phase-noise, and selectivity, with a consideration of worst-case interferers environment. The receiver sensitivity according to system-IIP3 and strength of blockers is shown (7)

$$Sensitivity = NF + 10\,log(\,KTB + P_{IMD}\,) + SNR_{demod}$$
$$[\,where,\; P_{IMD} = 3\sum(\,P_{max.blocker}\,) - 2IIP_3,\; SNR_{demod} = SNR_{min}\,, \quad (7)$$
$$P_{max.blocker} \cong P_{max} - 20\,log(\,4\pi \cdot distance \cdot f/c\,)\,]$$

Here, an IIP3 is related with a linearity performance of receiver. The PIMD is expressed by system-IIP3 and summation of maximum blockers generated from IEEE 802.11b and IEEE 802.15.1 stations. The Pmax represents a maximum blocker signal power; KTB is thermal noise power considering a bandwidth; SNRdemod is a SNR required by a baseband modem; f is a frequency; c is a light velocity, and distance is a range between IEEE 802.15.4 station and the source of blockers. According to distance in some channel environments, the signal power of blockers is exponentially decided through path-loss. Also, the path-loss can be calculated by an air channel modeling according to real environments. But, it is calculated by with assumption of the general free space channel condition. The relationship between sensitivity and distance according to system-IIP3 is shown in Fig.3. The blockers used in this analysis are generated from other communication systems: IEEE 802.11b and 802.15.1. In this graph, we can see the degradation of receiver sensitivity because of increasing the strength of blocker signal power according to shorting a distance. Also, we get a sight of the loss of sensitivity as lowering a system-IIP3. In particular, when less than ten-meters of distance, we can see the degradation of sensitivity. So, it is worthy of notice that a system-IIP3 is required by more than –10dBm for the receiver sensitivity of –95dBm against strong interferers at very shot range.

The receiver sensitivity according to phase noise of local oscillator and strength of blockers is shown (8)

$$Sensitivity = NF + 10\,log(\,KTB + P_{OSC}\,) + SNR_{demod}$$
$$[\,where,\; P_{OSC} = \sum P_{max.blocker} + Phase\ noise + 10\,log(\,BW\,), \quad (8)$$
$$P_{max.blocker} \cong P_{max} - 20\,log(\,4\pi \cdot distance \cdot f/c\,)\,]$$

Here, a Phase noise is related with a spectral purity performance of local oscillator. The POSC is expressed by LO-phase noise and summation of maximum blockers generated from IEEE 802.11b and IEEE 802.15.1 stations. Also, the frequency bandwidth of IEEE 802.1.4 is 2MHz. The relationship between sensitivity and distance according to LO-phase-noise is shown in Fig.4. The blockers used in this analysis are generated from other communication systems: IEEE 802.11b and 802.15.1. In this graph, we can see the degradation of receiver sensitivity because of increasing the strength of blocker signal power according to shorting a distance. Also, we get a sight of the loss of sensitivity as lowering a phase noise of LO. In particular, when less than ten-meters of distance, we can see the degradation of sensitivity. So, it is worthy of notice that a phase noise of LO is required by more than –110dBc at 1MHz-offset frequency for the receiver sensitivity of –95dBm against strong interferers at very shot range.

The relationship between sensitivity and distance according to system-IIP3 and LO-phase-noise is shown in Fig.5. The blockers used in this analysis are generated from other communication systems: IEEE 802.11b and 802.15.1. In this graph, we can see that sensitivity is dominantly impacted by interferes generated from 802.11b system than from 802.15.1 because of an emission of transmitters' higher output power under the FCCI and ETSI regulations.

The selectivity for in/out of-band channel selection must be determined for the specification of RF/IF/baseband

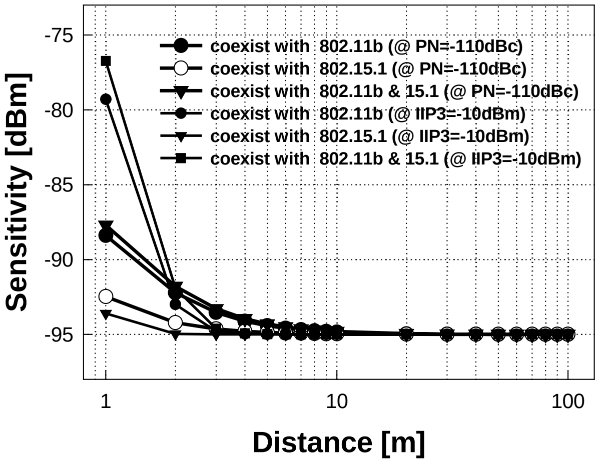

Fig.5 Sensitivity vs. distance for coexistence with various communication systems in 2.4GHz ISM-band.

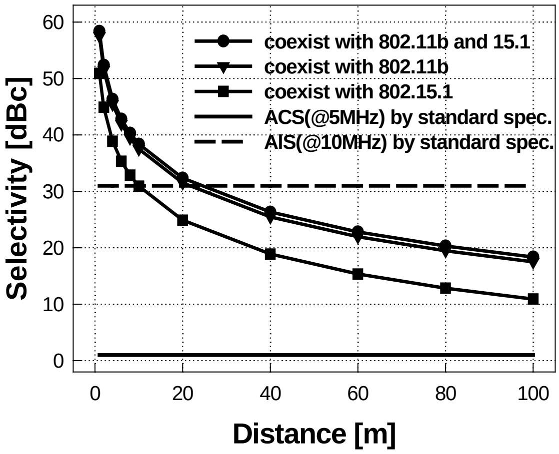

Fig.6 Selectivity vs. distance for coexistence with various

filters. The selectivity of a receiver against blockers generated from other communication system is shown (9). In this equation, we can see that the selectivity of receiver is decided by a signal power of blockers.

$$Selectivity = P_{max.blocker} - (MDS - SNR_{demod})$$
$$(SNR_{demod} = E_b / N_0 - PG_{despreading} + BB\_margin) \quad (9)$$

The MDS represents the minimum detectable signal, and SNRdemod describes a SNR required from baseband-modem. The relationship between selectivity and distance according to coexistences is shown in Fig.6. With 802.15.4 standard condition, the solid and dotted lines show the selectivity of receiver at 5 and 10MHz frequency offset, respectively. The other lines show the selectivity as signal power of blockers related a distance. In particular, when less than twenty-meters of distance, we can see a heavy requirement of selectivity. So, it is worthy of notice that it is required by more than –50dBc of the receiver selectivity against strong interferers at very shot range.

3. CONCLUSION

The desire for wireless connectivity has led an exponential growth in wireless communication. In particular, wireless sensor networks are potential wireless network application for the following future ubiquitous computing system.

This paper represents specifications required making a radio frequency (RF) receiver for low-rate wireless personal area networks (LR-WPANs), for coexistence with various wireless devices in 2.4GHz ISM-band. With IEEE 802.15.4 standard specification, it provides analysis of receiver performance requirements containing NF, system-IIP3, LO phase noise and selectivity. With some assumption, it illustrates relationship between a sensitivity of receiver and various situations considering for interferers generated from other wireless communication devices according to a distance. Here, we can infer the necessity of much tighter specification requirements than standard's that for various communication field

TABLE I
RF-SYSTEM PARAMETER FOR LR-WPAN

Requirements	Standard Spec. (IEEE802.15.4)	Reasonable Spec. (this paper)
NF / Sensitivity [dB/dBm]	25 / -85	14 / -95
IIP3 [dBm]	-32.4	-10.8
Phase noise (LO) [dBc/Hz, @1MHz]	87	-110
Selectivity [dBc, @5MHz]	1	52
Selectivity [dBc, @10MHz]	31	58

environments.

4. REFERENCES

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