Performance Increase in WSN by the Adaptation of Spreading Code Length

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Abstract: This paper demonstrates the possibility of increased throughput of WSNs by the adaptation of spreading code length. It is shown that for a given radio environment there is an optimized spreading code length which will maximise throughput and reduce energy usage. The optimum will depend on the available signal noise level due to background noise level or transmission distance in real deployments. A scheme of spreading code length adaptation has been proposed to archive the optimum throughput performance.

1. Introduction.

Wireless Sensor Networks (WSNs), which have been widely promoted over the last decade, are designed to monitor environment parameters, e.g. temperature, light, and humidity. Recently applications of WSNs have expanded into more advanced areas, for example: structural health monitoring, industry automation monitoring, and multimedia sensor network etc. In such applications, there is a requirement on WSNs to achieve high throughput and low delay while still maintaining energy efficiency.

It is well known that the IEEE 802.15.4 standard [1], one of the most popular solutions for WSNs, employs OQPSK with 32 chip Direction Sequence Spread Spectrum (DSSS) to provide a fixed 250kbps data rate. A recent commercial RFIC, the ATMEL AT86RF231 [2] provides 3 additional spreading code lengths (4 chip, 8 chip and 16 chip spreading modes), in addition to the standard mode. The motivation of this paper is to demonstrate that wireless sensor nodes equipped with this RFIC will be able to adapt their spreading length according to the quality of signal noise level to increase their throughput performance as well as power efficiency.

This paper will propose a scheme to optimize the throughput by understand the relationship between throughput and spreading length. Section 2 will provide the analytic model for different spreading lengths, while section 3 will analyse the results and propose a simple algorithm to utilize such effect. Section 4 will give conclusions and future work.

2. Throughput Model

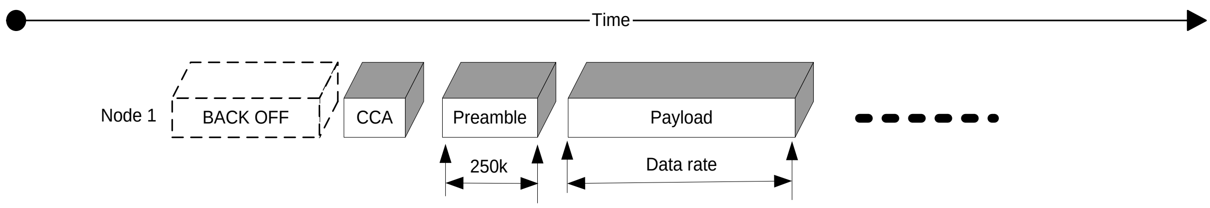


Figure 1. IEEE 802.15.4 un-slotted MAC scheme

The throughput of WSNs can be characterized by the MAC efficiency, the effective payload in each packet, and the Packet Receive Ratio (PRR).

Consider a transmitter and receiver pair. Both of them use the IEEE802.15.4 un-slotted MAC layer standard without ACK (scheme is shown in figure 1). Throughput could be calculated by:

$$TP = \frac{Payload \cdot PRR}{\mathrm{E}(T_{bo}) + \mathrm{E}(T_{CCA}) + \mathrm{E}\left(T_{tx}^{preamble}\right) + \mathrm{E}\left(T_{tx}^{payload}\right)} \quad (1)$$

where $E(T_{bo})$ is the expectation of Back Off (BO) time. Although the IEEE 802.15.4 MAC uses a binary back off scheme, as there is only one transmitter in the simple system considered here, the transmitter does not have the chance to enter other back off stages. This greatly simplifies the calculation. The value of $E(T_{bo})$ could be calculated by $\sum_{i=0}^{w-1} \frac{i}{w} \cdot 20 \cdot T_{symbol}$, in which $20 \cdot T_{symbol}$ is the period for each back off count and w = 8 means the backoff count is uniformly chosen from (0~7).

$E(T_{CCA})$ is the expectation of Channel Clear Assessment(CCA) time. According to [2], CCA for the 32 chip spreading length mode is 8 symbol periods and 2 symbol periods for the rest modes.

$E\left(T_{tx}^{preamble}\right)$ is the expectation of preamble transmit time at a data rate of 250kbps.

$E\left(T_{tx}^{payload}\right)$ is the expectation of preamble transmit time at a data rate from 250kbps to 2Mbps.

As shown in figure 1, in order to allow appropriate frame synchronization, different spreading codes are restricted to the payload part only, which means that all the PHY header and preamble are transmitted using the standard 32 chip spreading mode resulting in a BER performance difference with the payload part. Then PRR could be defined as:

$$PRR = (1 - BER_{preamble})^{8 \cdot l} \cdot (1 - BER_{payload})^{8 \cdot payload} \qquad (2)$$

where l is the length of preamble bits, $BER_{preamble}$ is the BER for preamble. $payload$ is the useful data length and $BER_{payload}$ is the BER for payload.

BER performance for OQPSK in AWGN channel, which is employed by IEEE802.15.4 as modulation scheme, can be simply calculated by using the Q function. Additionally, since DSSS technology is employed, the BER performance should be increased by the Code Gain (CG) and Processing Gain (PG). Then BER can be written as:

$$BER(E_b N_o) \cong 2 \cdot Q(\sqrt{2k \cdot E_b N_o \cdot CG \cdot PG} sin\frac{\pi}{4}) \qquad (3)$$

The processing gain is defined as:

$$PG = \frac{n}{k} \qquad (4)$$

where k is the number of bits carried in one symbol (in IEEE802.15.4 each symbol contains 4 bits of information) and n is the length of spreading code.

For DSSS code sequences, an approximate expression [3] for coding gain is:

$$CG \cong k \cdot \left(\frac{\bar{d}}{n} - \frac{ln2}{E_b N_o}\right) \qquad (5)$$

where $\bar{d}$ is the mean Hamming distance of a certain spreading code set.

We still lack the mean hamming distance of the spreading code used by the AT86RF231 for the 4 different modes ([2] did not provide such information), which is the key to calculate the coding gain. However [2] does provide the sensitivity for different spreading code lengths. Follow the same approach as [3], we can estimate the mean Hamming distance for each of the spreading code sets.

The sensitivity of receiver can be defined as the minimum signal power at the antenna.

$$P_{min} = kT \cdot W \cdot n_f \cdot SNR_{min} \qquad (6)$$

where k is Boltzmann's constant, T is absolute temperature, W is the communication bandwidth, n_f is the noise factor of the receiver (according to [4], AT86RF230's noise factor is 5.7dB) and SNR_{min} is the minimum baseband signal power to noise power ratio at the demodulator. As reported in [3], the combination of non-ideal demodulation and hard decision detection shows a sensitivity sacrifice of 6.6dB, which also contributes to P_{min} . SNR_{min} is defined as the sensitivity of receiver is the SNR level which enables maximum packet error rate (PER) of 1% for reference packet with 20 Byte and 6 Byte PHY header.

In [3] SNR_{min} has been expressed as: $SNR_{min} = 8.8dB - CG - PG$ for the standard IEEE802.15.4.

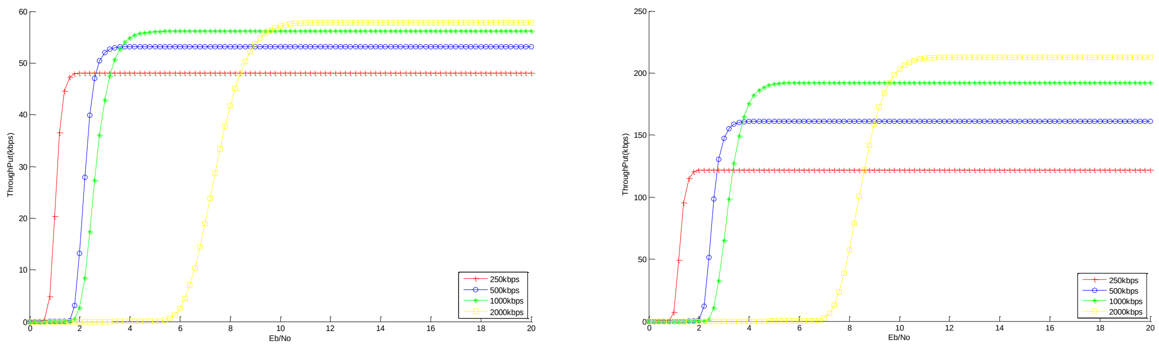
Similarly, in standard IEEE802.15.4 PG = 10*log10(32/4) = 9dB. By applying $\bar{d}$ and n to the combination of (4), (5) and (6), we are now able to calculate the sensitivity of different values of $\bar{d}$ and n. resulting in the following (table 1) set of mean Hamming distances which best approximate the sensitivity:

Table 1 Spreading sets in AT86RF231

Spreading length	Mean Hamming distance	Calculated sensitivity	Provided sensitivity	Data rate
32	17	-101.6075 dBm	-101 dBm	250kbps
16	7	-97.5889 dBm	-97 dBm	500kbps
8	4	-95.2761 dBm	-95 dBm	1000kbps
4	1	-88.3565 dBm	-89 dBm	2000kbps

Now it is able to calculate throughput performance for different spreading length by the combination of equations (1) - (5) and Table1.

3. Numeric Result Analysis



(a)Payload =20byte

(b)Payload =80byte

Figure 2 throughput performances against E_b/N_o for different spreading lengths.

Figure 2 is generated based on the model discussed in section 2. In figure 2, when the E_b/N_o is greater than 9.6dB, the 4 chip spreading length shows the best throughput due to the highest data rate. As the E_b/N_o decreases, the PRR for the 4 chip spreading length mode decreased rapidly, demonstrating that the 8 chip spreading length mode provides the best performance for E_b/N_o between 3.6dB~9.6dB. Similarly the 16 chip spreading is better in the region between 2.6dB ~ 3.6dB while 32 chip spreading is better below this value.

As the header and preamble are transmitted using the standard mode, longer payload lengths will achieve a higher throughput increase for the lower spreading length modes. This effect can be observed by the comparison of figure 2 (a) and figure 2 (b), which shows the different in performance of 20 and 80 byte payloads respectively.

Another issue worth noting is that the performance of 4 chip spreading mode is slightly worse than standard OQPSK, although both of them have the same data rate. It is because the PG for such a mode is 1 (i.e. no processing gain), while CG is negative for a 4 chip spreading mode which means a decrease of the BER performance. This explains why there is big distance between this mode and the rest of the modes in figure 2.

Finally it proves a simple but well known theory: although the highest data rate is archived with 4 spreading length (2000kbps), the best throughput offering in a given setting depends on value of E_b/N_o, which could been effected by the noise level or the distance between the transmitter and receiver. Although similar solutions have been employed in IEEE 802.11(although this uses the adaptation of modulation order rather than spreading code length), this is the first time that WSNs are able to archive higher throughput by the adaptation of the spreading code length.

A distinctive advantage that can be expected by applying this scheme in a sensor network is in the power efficiency. Although the AT86RF231 supported 4 different data rate, chip rates are the same for these 4 modes, which means the power consumption level is same for all modes. Therefore, if the data packet was transmitted at the higher data rate, the transmission time will be shorter, leading to the shorter active time and lower power consumption of the WSN devices.

The following algorithm based on the above observation is proposed to archive best performance:

Algorithm 1: Spreading Code Length Adaptation Algorithm

Trigger: the finish of each transmission process.

Variables: Received Signal Strength Indicator(RSSI), PRR

Rule 1: ***if*** PRR of last period is low than threshold

then switch to next longer spreading code length.

Rule 2: ***if*** PRR is approaching 100%, and RSSI is higher than threshold

then switch to next shorter spreading code length.

4. Conclusions and Future Work.

This paper examines the analytic model of network throughput based on the signal noise level for a node with adaptive spreading code length. A spreading code length adaptation algorithm is proposed, which allows WSN devices to archive optimum throughput performance in their radio environment. Although similar technology has been deployed in IEEE802.11, when such scheme is expended to large scale multi-hop sensor network, special consideration would be required and a significant performance increase could be expected.

In our future work, experiments with the AT86RF231 platform will be carried out to validate this model as well as extending such a model to large scale networks.

Acknowledgments.

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