# A Power Control MAC Protocol for Moving Target :on Wireless Sensor Network Testbed

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*Abstract*—**Energy efficient is the core issue in wireless sensor network (WSN), and many researchers have proposed many creative protocols towards this problem. However, most of them did not consider network with mobility, which challenges the performance of their presented schemes. To alleviate the concerns, we propose a Transmission Power Control (TPC) strategy, which enables sensor to dynamically control its output power according to the channel condition and mobility. Besides, we utilize a WSN testbed to evaluate our strategy, which contains the necessary components: programmable RF layer, software-defined MAC layer and adaptive network layer to fulfill our research requirements. It is based on system-on-chip processors which can develop large scale network and equipped with strong configure ability. And we make an experiment on our platform to reveal the performance of our scheme in saving energy, maintaining the link quality and extending network's lifetime.**

## I. INTRODUCTION

Wireless sensor network (WSN) has been applied to various fields including microclimate monitoring, tracking, battlefield monitoring and intelligent furniture because of its strong processing ability. Nodes in WSN have a series of characteristics. They are required to have self-organization capability and low power consumption. Besides, they must provide robust and efficient point-to-point communication [1].

Among all the features, the most important constraint is the node's energy consumption as devices are usually battery-powered and the large deployments are not easily accessible. MAC protocol has been at the core of decreasing the power cost because it controls the data transmission directly, which takes up 70% of the energy consumed by widely available embedded WSN platforms [2]. Consequently, large portion of WSN MAC protocols focus on Transmission Power Control (TPC) (e.g. in [3] [4] [5] [6] [7] [8]).

TPC contributes to improve the system's performance in several aspects. First, it maintains the transmission power above a certain threshold and increases the probability of successful data transmissions ( [3] [4] [5] [6]). Besides, with a higher output power, the Radio Frequency (RF) layer can use modulation and coding methods with a higher data rate [7] [8], enlarging the transmission bandwidth when heavy workloads occurs, or decreasing it to save energy. Finally, only nodes which share the same space contend to access the channel. This reduces the data collision probability and enhances network utilization efficiency [6]. Based on the above researches, we find that most of the existing TPC techniques did not consider the mobility of nodes, which has been introduced in many position systems and environmental monitoring systems. And also, few of the previous researches on TPC notice that an effective relay selection scheme combined with power control mechanism may contributes to increase WSN's lifetime and strengthen its robustness, especially under the case of poor channel quality or rapid mobility.

In this paper, we first design a power control mechanism for moving nodes in WSN by using received signal strength indicator (RSSI) as a feedback metric. Other work [2] has established a solid relationship between RSSI and signal-noise-ratio (SNR). When the sender initiates the transmission, it transmits a *preamble* before the DATA frame. If the receiver receives the *preamble* and is ready to receive the DATA frame, it feedbacks the RSSI value to the sender which announces the received power on the *preamble* signal. To achieve reliable links in the network, the system has a received SNR threshold, and the source compares the feedback RSSI with the SNR threshold to configure the output power of the DATA frame's transmission to a proper value. Thus the *preamble* has two functions: (1) Serving as a notification of the pending DATA frame transmission. (2) Achieving the information of the channel condition. To alleviate the effects on channel quality caused by node's mobility, the source combines the consecutive several RSSI values and estimates the channel quality's variation rate to provide a dynamic adjustment of the DATA transmission power. When it costs the sender considerable power to cover the channel attenuation, we introduce a relay selection scheme by using game to share the source's heavy load burden and extend the lifetime of the overall network.

Moreover, we build up a real time WSN testbed by using low power system-on-chip (SoC) programmable processors, CC1110 from TI to implement our power control strategy for moving targets and evaluate its performance. The programmable RF transceiver allows nodes to control its output power and transmission band. The upper software-defined MAC layer enables the spectrum analysis. The RSSI unit provides an accurate measurement of the received signal's strength from which the sender can judge whether the receiver is moving, how much its output power should be to maintain a power saving and reliable communication, and whether a relay selection is needed. The adaptive network layer support large scale WSN and the nodes' self-organization ability.

Our contributions are as follows:

- We propose and realize a power control mechanism for WSN with mobile nodes. And we introduce a relay selection strategy based on game theory which enlarges the network's lifetime and robustness. Moreover, we make extensive experiment to evaluate our power saving protocol's performance.
- We establish a WSN platform using SoC processors which is equipped with the basic functions of wireless sensor networks to be adaptive to different MAC protocols and it reduces the difficulty in establishing large scale network.
- The experiment result shows a high probability of successful transmissions and the reduction on energy consumption in a WSN with multiple moving nodes.

This paper is organized as follows: Section II reviews some related works. And we describe the system model and our energy saving mechanism with mobility considered in section III. Section introduces the architecture of our testbed. The experiment and results are shown in Section V. Finally, Section VI concludes this paper.

## II. RELATED WORKS

In this section, we review some related WSN energy saving mechanisms and their implementation.

In recent works, the authors of [9] and [10] proposed Traffic-Adaptive Medium Access protocol (TRAMA) and WiseMAC protocol, which introduce the node sleeping mechanism and constraint the node's energy consumption in a certain low level. But when some mobile nodes are added to the network, the two sleeping mechanism cause a large packet loss rate. The Lightweight Deployment-Aware Scheduling (LDAS) algorithm in [11] effectively solved the problem of low communication coverage caused by the sleeping mechanism. However, it did not provide the mechanism to implement the reliable and dynamic communication between nodes. There are some works consider the mobile nodes in WSN. For example, the Eavesdrop-And-Register (EAR) algorithm in [12] utilize the self-organization medium access control to supply the dependable communication between mobile node and fixed node. But it comes across a high packet collision probability which increases the nodes' energy consumption under the cases of large number of mobile nodes. Besides, the EAR strategy costs the extra head packets, which increases the source's overhead and decreases the transmission efficiency. The mobility-aware MAC protocol for sensor network (MS-MAC) in [13] enables the adjustment of the scheduling mechanism dynamically by referring the node's velocity, which is based on the Sensor-MAC (SMAC) in [14] and [15] and fails to consider the communication coverage and reliability. We utilize the TPC techniques other than nodes' sleeping mechanism. Our scheme monitors the received SNR value and channel quality to allow the sender output a proper power which provides a reliable and energy saving communication.

As for the researches on relay selection schemes using game theory, several strategies have been proposed (e.g. [16], [17]). The authors delivered a creative centralized power allocation algorithm in [16], in which the source node chooses the "best" node to assist transmission and improve the average throughput. However, this scheme assumes that the complete channel state information (CSI) is available, which brings considerable overhead and large amount of information about channel estimation. In [17], the author presented a distributed relay selection algorithm based on game that the source and the relay only need to exchange the relay's output power and the price of power without the cost of a central channel. However a large number of iterations are called for in reaching the static game equilibrium, which reduces the transmission efficiency. And the method to find the optimal solutions has a high calculation complexity, which cannot be endured by WSN nodes. Our algorithm uses the feedback character between the buyer and the seller other than the first order optimality condition, which reduces the calculation complexity to a large extent. We also introduce a tradeoff between the optimal results' accuracy and the number of iterations.

What should be pointed out is that few of the presented power control protocol have been tested under a practical environment. That is a crucial step of the application. Because many problems, which are neglected for theoretical analysis convenience (e.g. the overhead caused by the control head packets, the inaccuracy and time cost of spectrum sensing), will emerge in such a practical system, which is the foundation of algorithm's simplification and modification. Thus, we establish a WSN on the testbed by using SoC processors to implement our power control mechanism, which provides a reliable evaluation of our scheme's performance.

## III. SYSTEM MODEL AND MECHANISM DESIGN

This section first describes the system model and our TPC mechanism for stationary nodes. Based on this, we introduce how to extend this scheme to make it applicable to the WSN with mobility. Then our relay selection strategy which increases the network's robustness and lifetime is presented.

### A. System model and TPC mechanism for stationary nodes

We assume a path loss propagation model where the received signal strength solely depends on its distance to the transmitter. And the attenuation factor $\alpha$ is identical on all the transmission paths. Each node confirms to the listen-before-talk (LBT) principle, and it can transmit only after making sure that the channel is idle. The wireless link between any pair of nodes is an Additive White Gaussian Noise (AWGN) channel with the bandwidth $W$. The spectrum density of the ambient noise is $N_0$ and we denote the total noise observed by a wireless link as $N = WN_0$ which is a constant everywhere in the network. The lower bound of the capacity at the destination $\underline{C}$ is given as:

$$\underline{C} = W \log_2(1 + \underline{SNR_{rec}}), \tag{1}$$

so $\underline{SNR_{rec}}$, which is the threshold of the received SNR to maintain a reliable transmission, can be expressed as:

$$\underline{SNR_{rec}} = 2^{\frac{\underline{C}}{W}} - 1. \tag{2}$$

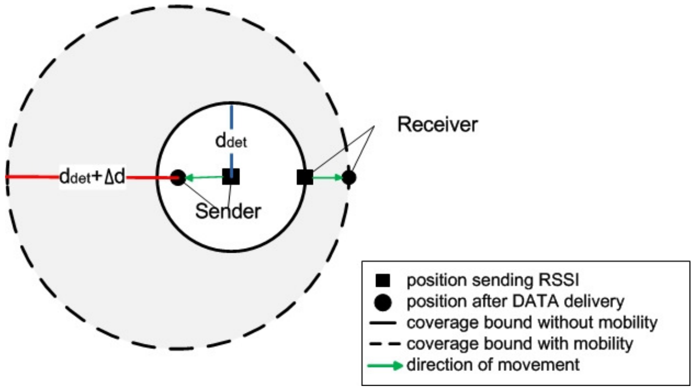

Fig. 1. Coverage extension in WSN with mobility

In our scheme, the source initiates the transmission by sending the *preamble* signal with the upper bound of output power $\overline{P_{out}}$, which considers the output ability of sensor and is intended to avoid putting a heavy load on a specific node. When the destination receives the *preamble* successfully, it feedbacks a signal on the RSSI value to the source and enters into the ready-to-receive state. The RSSI can provide a precise measurement on the received power at the destination which is the sum of the *preamble* signal power $P_{rec}^{pre}$ and the noise power $N$. If the sender does not receive the feedback signal when collision occurs, it retransmits the signal after the time $T_{wait}$. If the sender receives the feedback signal from the receiver, the output power in the DATA frame's delivery $P_{out}^{data}$ can be achieved as:

$$P_{out}^{data} = \frac{SNR_{rec} \times N}{P_{rec}^{pre}} \overline{P_{out}}, \qquad (3)$$

Our scheme allows the sender to utilize the feedback signal about the RSSI value from the receiver. The source would adjust its output power dynamically to keep the received SNR above the preset threshold, which prevents the sender from transmitting with too high a power (waste of energy) or too low a power (packet loss and retransmission reduce the energy efficiency).

### B. The extension of TPC for mobile nodes

As for the WSN with mobility, we assume the maximal speed of nodes be $\overline{v}$ and the time between the delivery of RSSI and the DATA frame's termination be $\tau$. The above dynamic power control scheme has a poor performance under the circumstances of rapid mobility and long DATA frame transmission. Because the sender transmits with $P_{out}^{data}$ which is simply achieved from the channel condition when the receiver feedbacks the RSSI. And we should note that $P_{out}^{data}$ may not be able to provided a reliable link due to the variant attenuation effect caused by moving nodes during $\tau$.

**Algorithm** TPC scheme for WSN with mobility

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Require: threshold of received SNR $\underline{SNR_{rec}}$, noise power $N$, path loss factor $\alpha$, node's maximal speed $\overline{v}$, time between RSSI's delivery and DATA frame transmission's end $\tau$
Sender transmits preamble with $\overline{P_{out}}$ to the receiver
if no feedback signal about $P_{rec}^{pre}$ received then
    repeat
        Sender waits for $T_{wait}$, then retransmits preamble.
    until sender receives the feedback signal about $P_{rec}^{pre}$
end if
Sender calculates $P_{out}^{data}$ from (3) and detects $d_{det}$ based on path loss model and $P_{rec}^{pre}$
Sender achieves $\Delta P_{max}$ from (6)
$\Delta P \leftarrow \Delta P_{max}$
repeat
    count←0
    for i=1 to K do
        $P_{mob-out}^{data} \leftarrow P_{out}^{data} + \Delta P$
        Sender transmits one data packet with $P_{mob-out}^{data}$
        if successful transmission then
            count++
        end if
    end for
    if count>M then
        $\Delta P \leftarrow \Delta P - 0.1\Delta P_{max}$
    end if
    if count<M then
        $\Delta P \leftarrow \Delta P + 0.1\Delta P_{max}$
    end if
until DATA frame transmission termination
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We define the maximal power offset $\Delta P_{max}$ to expand the coverage which considers the channel condition's variation under the worst case (shown in Fig.1): the two nodes depart from each other in the opposite directions at the speed $\overline{v}$. Thus, $\Delta d_{max}$, which is the maximal variation of the distance between sender and receiver within $\tau$ is:

$$\Delta d_{max} = 2\overline{v}\tau. \qquad (4)$$

In the path loss propagation model, $d_{det}$ , which is the distance between the sender and the receiver at the time of RSSI transmission, can be calculated from the received power $P_{rec}^{pre}$ and the output power of *preamble* signal $\overline{P_{out}}$. Therefore, the maximal power offset $\Delta P_{max}$ which maintains the reliable link under the worst case should fulfill:

$$\frac{P_{rec}^{pre}}{\overline{P_{out}}}\left(\frac{d_{det}}{d_{det}+\Delta d_{max}}\right)^{\alpha}(P_{out}^{data}+\Delta P_{max}) = \underline{SNR_{rec}}\times N. \qquad (5)$$

So the maximal power offset can be expressed as:

$$\Delta P_{max} = \left[\left(1+\frac{\Delta d_{max}}{d_{det}}\right)^{\alpha}-1\right]P_{out}^{data}. \qquad (6)$$

We utilize $\Delta P_{max}$ to normalize and estimate the proper power offset for each pair of nodes. The source initially use the maximal power offset. If the destination receives successfully for consecutive $K$ packets which means that the mobility's effect on the link's reliability can be repressed by the current power offset, the sender reduces its power offset by 10%. If the destination loses $M$ in $K$ packets, in other words, the sender needs to extend its coverage to maintain the reliable link, the source increases its power offset by 10%. Then this process

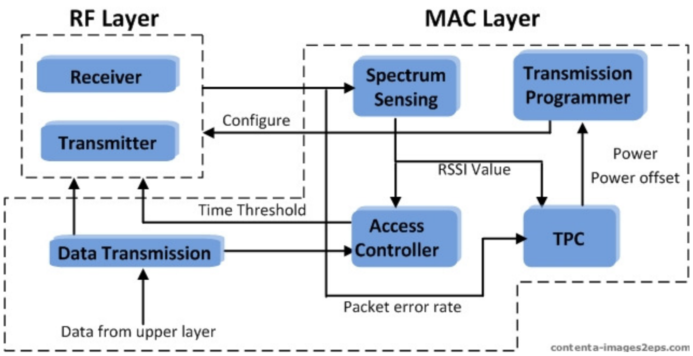

Fig. 2. The architecture of our testbed

continues in iterations and it implements the dynamic control on the power offset $\Delta P$ and the output power in mobile WSN $P_{mob-out}^{data}$ is given as:

$$P_{mob-out}^{data} = P_{out}^{data} + \Delta P. \tag{7}$$

Our algorithm's procedure is listed in pseudo-code as above.

## IV. ARCHITECTURE OF OUR TESTBED AND PROTOCOL IMPLEMENTATION

In this section, we present the architecture of our testbed. Firstly, we will give a brief introduction about the hardware ability and the development environment of our platform. Then we will present our platform?s basic blocks which facilitate the evaluation of our TPC algorithm for WSN with mobility. CC1110 is a low-power SoC processor based on industry- standard 8051 Micro Controller Unit (MCU) which is equipped with state-of-the-art RF transceiver aiming at wireless applications. To answer the requirement of the connection to the external world, two programmable USARTs interfaces are provided to exchange the control and communication data. And also, three 8-bit timers and one 16-bit timer are installed which can be used to control the traffic character and access time of the nodes. The MAC algorithm can be realized as high level programming language: C++/C codes which support rapid prototyping.

### *A. The Programmable Radio Frequency (RF) Layer*

The RF transceiver is programmable and the transmission power, frequency, modulation method and data rate can all be controlled by setting the value of special function registers (SFR). The transmission channel can be selected from three ISM bands: 300.0-348.0 MHz, 391.0-464.0 MHz and 782.0-928.0 MHz, and each ISM band can be divided into about 20 sub-bands. CC1110 provides several modulation methods with GFSK, MSK, ASK and 2FSK included. The data rate of CC1110 can be set ranging from 1.2 kBaud to 500 kBaud.

### *B. The MAC Layer*

The MCU can be adaptive to our TPC scheme through configuration, which is illustrated in Fig. 2. The spectrum sensing block which is based on RSSI could provide reliable measurement of the channel condition. And the TPC block calculates the optimal output power with the knowledge of the feedback RSSI value and it keeps monitoring the packet error rate, which decides the modification of the power offset $\Delta P$. The TPC block enables the Transmission Programmer to configure the RF layer and implement our strategy in the physical layer. The access controller decides whether it is "safe" to utilize the channel in case of collision.

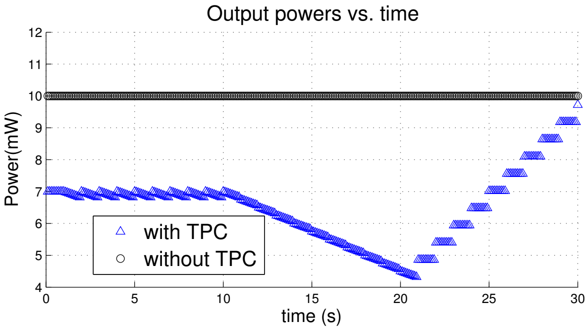

Fig. 3. Point-to-point output power over time

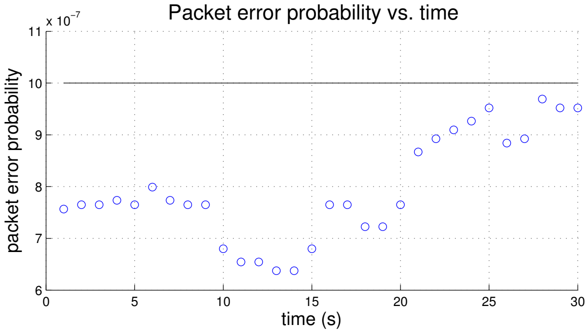

Fig. 4. Packet error probability over time

## V. EXPERIMENT AND RESULTS

In this section, we design some experiments based on our testbed to evaluate out TPC scheme. First, we build the point-to-point transmission scenario: the channel is set at 433.5 MHz with the bandwidth 300 kHz and the data rate is 200 kBaud with the modulation method GFSK.

The experiment last for 30 seconds. During the first 10 seconds, both of the two nodes are stationary. And in the second 10 seconds, the two nodes move toward each other at the speed $v = 3m/s$. In the last 10 seconds, the two sensors moves in the opposite direction at the upper bound of their speed $\overline{v} = 8m/s$.

From Fig.3, we can see the output power of the sender during the 30 seconds. When the two nodes are fixed, the output power is almost unchanged. And there is a tiny fluctuation whose period is around 1 s, because 1) the sender updates the channel condition per second; 2) The initial maximal power offset for mobility (worst case) is more than enough for stationary pair of nodes. When two nodes moves towards each other, there is a decreasing trend for the output power, because the channel condition becomes better. As for the worst

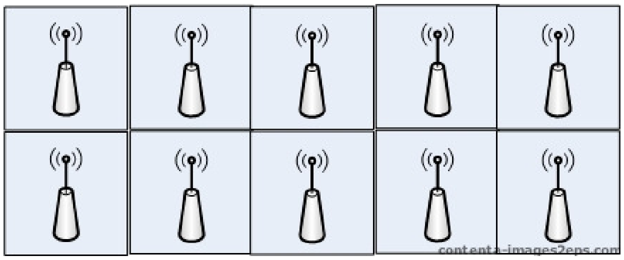

Fig. 5. The experiment scenario of 2×5 grid sensor network

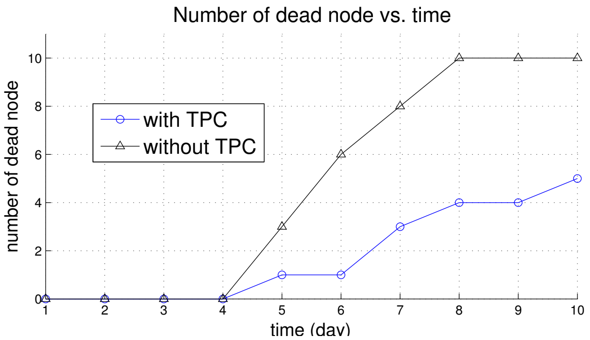

Fig. 6. Number of "Dead Nodes" over days (overall 10 nodes)

case, the output power keeps increasing, and during the gap between two channel condition update, the output power is almost constant. Because under the worst case, the power offset equals to $\Delta P_{max}$, and any decrement on the power offset leads to the increment on the packet error rate (due to the worse channel consition). And our algorithm will increase the offset back to $\Delta P_{max}$. Through the comparison with nodes without our TPC scheme, we can see that our algorithm saves more than half of the transmission power. And in Fig. 4, we show the packet error rate over time, in which our strategy maintains the packet error rate below $10^{-6}$, even under the worst case. Thus, our strategy is able to suspend a high quality link even under the condition of rapid mobility.

Besides, we construct a $2 \times 5$ grid network, in which each node has the same amount of data to transmit (illustrated in Fig. 5), in order to check our algorithm's energy saving performance towards a whole network. We define "Dead node" as follows: the node whose remaining energy is less than its battery capacity. And we monitor the number of dead node's growth over days, which is illustrated in Fig. 6. We can see that the growth of "Dead Node" in the network with our scheme is much slower than that in the network without our TPC technique (nodes have the same throughput), in other words, our TPC scheme extends network lifetime.

## VI. CONCLUSION

In this paper, we present a TPC scheme for WSN with mobility, which is energy efficient and maintain a good link quality (low error rate) even under rapid mobility condition. Besides, this algorithm extend network's lifetime and make it more robust. Apart form that, we utilize a WSN testbed based on CC1110, which answers our research requirements of both lower hardware layer and upper MAC layer, and we establish an experiment to verify the performance of the TPC scheme.

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