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Abstract—**Distributed Source Coding (DSC) based signal processing applications are ideal candidates for multirate transmissions in Wireless Sensor Network (WSN). In this paper, we propose a novel MAC-PHY approach in WSN to achieve energy efficiency using multirate desirable for the DSC based signal processing applications. Our approach is different from the common multirate research in link adaptation, the focus of which is to increase throughput based on rate adaptation derived from variable channel conditions. In the proposed approach, the redundant and inefficient communications are eliminated, yielding significant improvement of energy efficiency in WSN. Here, the minimum desirable transmission power can be determined and employed based on the desirable Bit Error Rate (BER), the channel attenuation, the corresponding modulation scheme, and the multirate requirements. Simulation results show this approach achieves considerable energy efficiency in WSN while maintaining the transmission quality.**

Index Terms—Energy Efficiency, Multirate, Wireless Sensor Network, Distributed Source Coding

I. INTRODUCTION

The Distributed Source Coding is a newly developed area in the WSN [1], [2] where the energy consumptions for communications can be improved by the unique feature of DSC. In this case, the information redundancy among correlated sensors is removed without mutual communications or information exchanges between these sensors, or between the data streams collected by these sensors. Additionally, DSC has the preference of multirate support in networks, particularly in real-time applications. In a DSC application, each source node collects information and sends data to sink node independently, via a different routing path at a different data rate. It is thus desirable for WSN to provide a support for multirate transmission platform, driven by the need of upper layers of network (i.e., application), to achieve energy efficiency. This is different from the common multirate research in Wireless Local Area Network (WLAN), where the focus is to increase throughput based on rate adaptation from the variable channel conditions. How this multirate requirement of DSC can be met in WSN architecture, and more critically, how this feature of DSC can be exploited for increasing the WSN energy efficiency significantly, have not been researched much in the literature. *On the other hand, due to the nature of distributed and collaborative signal processing in WSN, these multirate data transmission requirements in DSC are not limited to a small category of applications, but are rather general in many signal processing related WSN applications* such as audio [3], image [4] and video coding applications [5] [6].

There are multirate designs for Mobile Ad-hoc Network (MANET) (e.g., [7] [8]), which are mainly oriented to throughput maximization. Other researches related to multirate and power control have been conducted extensively for Code Division Multiple Access (CDMA) system [9]-[14], and they aim to reduce Multiple Access Interference (MAI) and increase channel capacity. Using spreading gain can achieve low power; however, it does not necessarily result in low energy consumption. The major difference between our work and the existing approaches for multirate networks (in the contexts other than WSN) is that we are intensively focused on improving WSN energy efficiency. This higher-priority goal leads to two important design principles different from the earlier ones are; (1) WSN explores variable transmission rates demanded or desired for the DSC in the distributed and collaborative signal processing context, and (2) WSN provides low-energy multirate communication platform at lower layers based on such explorations. While the state-of-the-art designs in WSN strive to achieve energy efficiency in many aspects [23]-[26], few approaches provide multirate functionality suitable for DSC applications.

Our work focuses on providing a multirate solution supporting the multirate and distributed traffic in DSC applications, while achieving energy efficiency which is an important factor in WSN. The dynamic rate selection functions have a great interaction with the modulation and power scaling at physical layer, therefore taking a MAC-PHY approach is a logical approach. In our solution, the rate and power control are implemented into a MAC-PHY plug-in, residing partly between MAC and PHY layers. We also adopt the medium access and wakeup-sleep mechanisms of MAC protocols in WSN due to their effectiveness in achieving energy efficiency. Based on the interaction between DSC applications, the multirate requirements and the WSN channel status, variable data rates are provided by changing modulation schemes,

which results in achieving energy efficiency significantly.

The rest of paper is organized as the following. In Section II, we give a background review of related works and highlight the significance of our work. In Section III, we derive the quantified relation between the transmit power and BER. In Section IV we propose our WSN energy efficient multirate scheme in MAC-PHY approach. With this scenario, Section V gives a comprehensive energy analysis which shows theoretically the advantage of our scenario in energy efficiency. Section VI presents the simulation and performance data evaluation. Conclusion is drawn in Section VII finally.

II. RELATED WORKS

There are some existing multirate MAC layer protocols for WLAN such as 802.11a/b/g [7] [8] [17] [18] in which the data rate could dynamically change according to the SNR at the receiver end. However, most of these works' primary goal is to increase the throughput rather than energy efficiency. A few consider energy efficiency issues by provide power saving modes [19]-[21], in which individual nodes periodically listen and sleep, however, these works still don't address the goal of high energy efficiency required by WSN. Further, these works are usually designed with the presumption that all nodes are located in a single network cell. Adaptations for multi-hop networks have been proposed, but it requires more complexity and more dynamic states than what would be available generally in WSN [22].

Many researches related to multirate and power control have been extensively conducted in CDMA area [9]-[14]. Their primary goal is to maximize channel utilization [11] [12] or minimize the interference and the near-far effect [13] [14]. In those works, lower rate transmissions with higher channel coding redundancy may result in lower power consumption, reduced channel interferences and increased system capacity. However, besides the implementation complexity, an extension of this scenario to WSN with power efficiency does not necessarily lead to energy efficiency for DSC application in WSN due to high redundancy, unfortunately. As a result, the multirate and power control schemes in these works are not suitable for WSN. In contrast, our approach is to fine tune a simple WSN multirate communication platform based on the DSC inherent multirate requirement, manipulate the power supply and achieve the significant energy efficiency.

Many designs of MAC protocols suitable for WSN have been well proposed and studied. For example, S-MAC [23] and T-MAC [24] are low power contention based MAC protocols, but they are based on single rate transmissions and do not provide multirate support for upper layer DSC applications. B-MAC [25] has a simple MAC core and a versatile interface, with high throughput and energy efficiency. Z-MAC [26] employs CSMA as the baseline MAC scheme, and uses a TDMA schedule as a hint to help contention resolution. Unfortunately, B-MAC and Z-MAC are still based on single rate transmissions, inapplicable for DSC multirate requirements. It is clear that these WSN MAC protocols require

sensor nodes have to transmit data in a burst at single data rate and then go back to sleep during DSC applications. This is not a best strategy for multiple data rate DSC applications in terms of the energy efficiency, as demonstrated later in Section VI.

So far as we know, there have been *no multirate transmission schemes, and the corresponding PHY-MAC designs proposed in WSN*. Our approach is based on modifying the existing WSN MAC protocols (e.g., T-MAC) to accomplish the multirate transmission scheme while keeping their effectiveness in medium access and duty cycle management. We add the DMS (Dynamic Modulation Scaling) to achieve multiple data rates and DPS (Dynamic Power Scaling) to provide energy saving. Although we consider T-MAC specifically in the following sections, the proposed multirate scheme is not confined to it and can be easily extended to other appropriate MAC protocols.

III. TRANSMIT POWER AND BER

In this section, we give the physical layer theoretical relationship between the targeted BER at receiver's side and the transmit power at the sender's side in an AWGN channel, with closed form equations presented.

In the wireless environment, the desirable BER value can be mapped to a Signal Noise Ratio (SNR) value and a desirable transmission power value, given the modulation scheme, and data rates. In this paper, we consider BPSK (Binary Phase Shift Keying), QPSK (Quadrature Phase Shift Keying) and QAM (Quadrature Amplitude Modulation) specifically. Nowadays BPSK and QPSK are widely used in WSN. With the increasing bandwidth requirements from video and audio sensors targeted at signal processing applications, QAM modulations may be introduced to improve the bandwidth utilization [15] [16].

Equations (1) and (2) are the relationship between the desirable BER and transmit power, for BPSK, QPSK and QAM modulations respectively, which can be straightforwardly derived from [27]-[29], [35]:

$$Ps^{BPSK,QPSK} = Rs \cdot b \cdot \left[erfc^{-1}(2 \cdot BER) \right]^2 \cdot \frac{N_0}{A} \tag{1}$$

$$Ps^{M-QAM} = \frac{1}{3} \cdot Rs \cdot b \cdot (b^2 - 1) \cdot \left[erfc^{-1}\left(\frac{1}{2} \cdot \left(1 - \frac{1}{b}\right)^{-1} \cdot BER \right) \right]^2 \cdot \frac{N_0}{A} \tag{2}$$

When modulation scheme is determined, symbol rate *Rs* and constellation size *b* is also determined accordingly. Desirable BER is a system parameter, pre-defined by the system. Gaussian noise power intensity *No* is a system constant value. Channel attenuation with antenna gain *A* can be calculated from lower layer. So from the above analysis, all the factors on the right sides of Equation (1) and (2) can be determined. As a result, the transmit power can be calculated from Equation (1) and (2).

From Equation (2), it is critical to see that the decrease of data rate is disproportionate to the decrease of supply power. Without considering the interferences, transmitting data at a lower data rate with a more robust QAM modulation scheme achieves better energy efficiency at the PHY layer, compared with the higher data rate transmission. In our WSN DSC applications, this principle is employed to fine tune the

trade-off between WSN multirate schemes and DSC multirate requirements, achieving better energy efficiency without increasing much interference.

In next section, we describe how to implement this fine-tuning with rate and power control in a MAC-PHY approach.

IV. PROPOSED RATE AND POWER CONTROL APPROACH

A. MAC-PHY Architecture

In this section we propose an energy efficient MAC-PHY scheme providing a set of achievable data rates required from upper layers. The proposed MAC-PHY architecture is shown in Figure 1.

The desirable BER can be configured as a system parameter, and the data rate requirement comes from network layer as a user parameter. MAC layer matches the input data rate requirement with a lookup table, shown in Table 1. According to the data rate requirement, corresponding modulation scheme is acquired from the lookup table. The value of A can be calculated from the ratio between a given signal's SNR at the receiver and the same signal's SNR at the transmitter. The modulation scheme together with the channel attenuation and the desirable BER are guided into the Transmit Power Controller (TPC), to determine the proper transmit power and control the supply power of radio module correspondingly. The TPC accomplishes this task using Equation (1) and (2), and provides it to radio, to assure the desirable BER requirement at receiver. Similarly, the modulation scheme acquired from the lookup table according to the required data rate is also set to radio. Once these settings are complete, data transmission in physical layer will start and the data will be transmitted at the selected data rate with the corresponding modulation scheme.

The desirable BER is a pre-defined system parameter, and this parameter can be modified or updated. Network layer sets the rate requirement as user parameter to MAC layer. Then, the MAC layer is ready to transmit data to the corresponding neighbor nodes. The MAC layer enables and initializes radio, performs carrier sense contention for channel and sends RTS to intended receiver. When CTS packet is received, the channel attenuation factor A is calculated. The RTS and CTS packets are sent via basic modulation scheme with maximum power, since before data transmissions, the receiver has no knowledge of what modulation scheme the sender will utilize. The handshake of RTS-CTS provides a mechanism of modulation scheme negotiation and channel attenuation acquisition. And then modulation scheme is chosen by looking up the data rate: modulation mapping in the lookup table. After computing proper transmit power according to Equation (1) and (2) and supplying this power to radio, the sender starts transferring data via the chosen modulation scheme with the calculated transmit power. Once the transmission is finished, MAC layer will reset the radio to the basic modulation scheme and the control packet such as RTS and CTS will be sent at this data rate and modulation scheme.
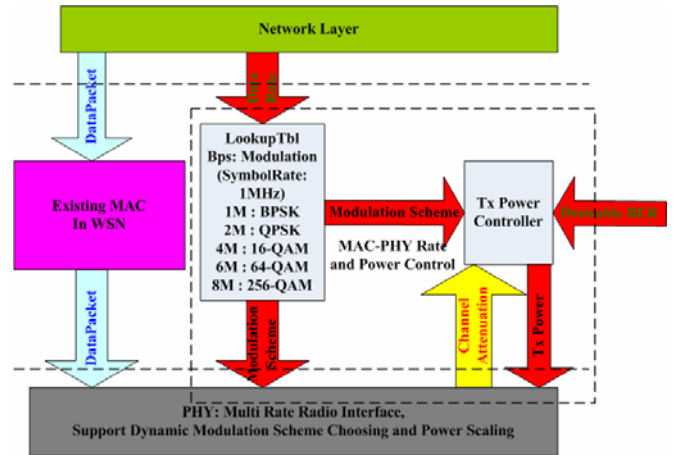

Figure 1. Multirate MAC-PHY Architecture

Data Rate (Mbps)	Modulation Scheme
1	BPSK
2	QPSK
4	16-QAM
6	64-QAM
8	256-QAM

Table1. Data Rate and Modulation Scheme Lookup Table

Previous researches on channel prediction and acquisition focus on heuristic approaches using RTS-CTS handshakes [30] [31], with simple implementation but high communication overhead; or mathematical approaches using past channel conditions to predict future ones [32] [33], with low communication overhead but high computation complexity. WSN MAC often has RTS-CTS inborn and requires low-complexity implementation. In our design we take heuristic approach, however our work is also extendable to other channel prediction and acquisition approaches. To get channel attenuation factor A, consider a general example of the data transmission between two nodes, shown in Figure 2. While sending RTS packet, Node 1 saves the SNR (Tx_SNR) of this RTS packet, for future calculation of channel attenuation. When Node 2 receives the RTS packet from Node 1, it measures this RTS packet's SNR (Rx_SNR) and sends CTS packet to Node 1.
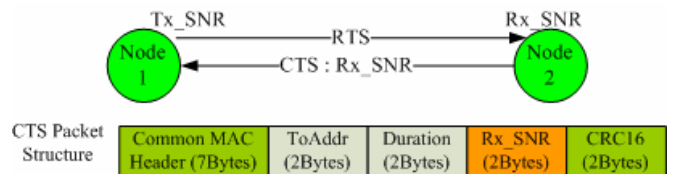

Figure 2. Getting Channel Attenuation Using RTS packet's SNR at Tx and Rx end. CTS Packet Structure, Adding 2-bytes Rx_SNR for Piggy Back to Sender

The channel attenuation factor A can be calculated by Rx_SNR and Tx_SNR.

$$A = Rx\_SNR / Tx\_SNR \tag{3}$$

Equation (3) gives the expression of how to get channel attenuation factor from the received SNR of RTS packet and the transmitted SNR of RTS packet.

B. Controlling Radio in MAC

Our design can be synthesized into different MAC protocols. In this subsection, we describe the sub interface between the proposed MAC layer and the physical layer radio module. We use T-MAC as an exemplar MAC protocol to show how to synthesize multirate functionality with existing MAC protocol and physical layer. The following code is extracted from T-MAC, showing how to couple MAC and PHY via rate and power control. In MAC the real data transmission is performed by *sendDATA* function. Before *PhyComm.txPkt* (physical bit stream transmission) the modulation scheme is set and the transmit power is calculated, and provided to radio module. After the physical layer's bit stream transmission, *PhyComm.txPktDone* event is triggered, and the modulation scheme is set back to the basic mode.

```
void sendDATA()
{
    setupPkt((MACSyncPkt*)dataPkt,DATA_PKT);
        //Here Choose proper Modulation Scheme:
        call PhyRadioCtrl.SetModulationScheme(\
            TOS_MODULATION_QAM16);
        uint_8 nPower = TxPowerCalcUnit.GetTxPower(\
            nChannelLoss , nTargetBER , \
            TOS_MODULATION_QAM16 );
        call PhyRadioCtrl.PowerSupply(nPower );
    //Here start physical layer's transmission
    call PhyComm.txPkt((PhyPktBuf*)dataPkt, txPktLen);
    state = TX_PKT;
}

    event result_t PhyComm.txPktDone(PhyPktBuf *packet)
    {
    // Restore the radio modulation to the basic scheme, \
        //where RTS CTS ACK are transmitted
        call PhyRadioCtrl.SetModulationScheme(\
            TOS_MODULATION_BPSK);
    call RadioState.idle();// Idle the radio
    return SUCCESS;
    }
```

From the above codes we can see that multirate functionalities are very easy to be synthesized into T-MAC.

V. MAC LAYER TRANSMISSION ENERGY ANALYSIS

At the beginning of transmission, sender transmits RTS packet to its neighbors to reserve channel. After sending out RTS packet, the sender turns to receive the CTS packet from the intended receiver. If after some time for a time-out value, the sender does not receive CTS from receiver, the former RTS is regarded as failed by the sender. Let BER be the desirable bit error ratio, the probability and the energy cost of a RTS packet failure due to collision and transmission error are expressed as Equations (4) and (5). Here L_{RTS} is the RTS packet length; p is the probability of a single node sending packet, N is the neighbor count of that node; P_{RTS}^{TX} denotes the power required for transmitting RTS packet, T_{RTS} denotes the RTS transmission time, P^{RX} denotes the receive power, and $T_{CTS\_timeout}$ denotes the time out value of receiving CTS packet:

$$p_{RTS}^{Fail} = 1 - (1 - BER)^{L_{RTS}} \cdot p \cdot (1-p)^N \tag{4}$$

$$E_{RTS}^{Fail} = P_{RTS}^{TX} \cdot T_{RTS} + P^{RX} \cdot T_{CTS\_timeout} \tag{5}$$

Upon receiving RTS from the sender, the receiver will respond with a CTS message to notify its neighbor that it is ready for receiving data. The probability and energy cost of receiving CTS packet failure is denoted as p_{CTS}^{Fail} in Equations (6) and (7):

$$p_{CTS}^{Fail} = (1 - p_{RTS}^{Fail}) \cdot \left(1 - (1 - BER)^{L_{CTS}}\right) \tag{6}$$

$$E_{CTS}^{Fail} = P_{RTS}^{TX} \cdot T_{RTS} + P^{RX} \cdot T_{CTS\_timeout} \tag{7}$$

The sender will transmit data packets only if it receives CTS packet from its intended receiver successfully. DPS and DMS are only used in DATA transmissions. The RTS, CTS and ACK packets are transmitted at the most robust data rate and modulation scheme with the maximum power, while data packets are transmitted using scaled modulation scheme and power. The probability and energy cost of sending DATA packet failure are expressed in Equations (8) and (9):

$$p_{DATA}^{Fail} = (1 - p_{RTS}^{Fail}) \cdot (1 - p_{CTS}^{Fail}) \cdot \left(1 - (1 - BER)^{L_{DATA}}\right) \tag{8}$$

$$E_{DATA}^{Fail} = P_{RTS}^{TX} \cdot T_{RTS} + P^{RX} \cdot T_{CTS} + P_{DATA}^{TX} \cdot T_{DATA} + P^{RX} \cdot T_{ACK} \tag{9}$$

After successfully receiving data, the receiver responds the sender with an ACK packet. The probability and energy cost of sending ACK packet failure are expressed in Equations (10) and (11):

$$p_{ACK}^{Fail} = (1 - p_{RTS}^{Fail}) \cdot (1 - p_{CTS}^{Fail}) \cdot (1 - p_{DATA}^{Fail}) \cdot \left(1 - (1 - BER)^{L_{ACK}}\right) \tag{10}$$

$$E_{ACK}^{Fail} = P_{RTS}^{TX} \cdot T_{RTS} + P^{RX} \cdot T_{CTS} + P_{DATA}^{TX} \cdot T_{DATA} + P^{RX} \cdot T_{ACK\_timeout} \tag{11}$$

Based on the four-way hand shake nature, the probability and the energy cost of sending a packet successfully is expressed in Equations (12) and (13):

$$p^{SUCC} = (1 - p_{RTS}^{Fail}) \cdot (1 - p_{CTS}^{Fail}) \cdot (1 - p_{DATA}^{Fail}) \cdot (1 - p_{ACK}^{Fail}) \tag{12}$$

$$E^{SUCC} = P_{RTS}^{TX} \cdot T_{RTS} + P^{RX} \cdot T_{CTS} + P_{DATA}^{TX} \cdot T_{DATA} + P^{RX} \cdot T_{ACK} \tag{13}$$

The average energy consumption of transmitting an upper layer data PDU can be expressed as $\overline{E}$ in Equation (14):

$$\overline{E} = E^{SUCC} \cdot p^{SUCC} + E_{RTS}^{Fail} \cdot p_{RTS}^{Fail} + E_{CTS}^{Fail} \cdot p_{CTS}^{Fail} + E_{DATA}^{Fail} \cdot p_{DATA}^{Fail} + E_{ACK}^{Fail} \cdot p_{ACK}^{Fail} \tag{14}$$

Considering the energy cost of transmitting an upper layer PDU with the length of L_{DATA}, we can rewrite Equation (14) into a simpler form (17):

$$C_0 = \left(p^{SUCC} + p_{DATA}^{Fail} + p_{ACK}^{Fail}\right) \cdot \left(P_{MAX}^{TX} \cdot T_{RTS} + P^{RX} \cdot T_{CTS} + P^{RX} \cdot T_{ACK}\right) + E_{RTS}^{Fail} \cdot p_{RTS}^{Fail} + E_{CTS}^{Fail} \cdot p_{CTS}^{Fail} \tag{15}$$

$$C_1 = \left(p^{SUCC} + p_{DATA}^{Fail} + p_{ACK}^{Fail}\right) \cdot L_{DATA} \tag{16}$$

$$\overline{E} = C_0 + C_1 \cdot \frac{P_{DATA}^{TX}}{R_{DATA}} \tag{17}$$

From Equations (1) (2) and (17) we can express transmission energy consumption with different rates and modulation schemes in Table 2. From Table 3, it is clear that except from BPSK to QPSK, which consume almost the same average transmission energy, all others increase data rate while increasing average transmission energy consumption.

Modulation Scheme	Theoretical Energy Consumption of Transmitting a PDU with length of L_{DATA}
BPSK	$\overline{E} = C_0 + C_1 \cdot \left[erfc^{-1}(2 \cdot BER) \right]^2 \cdot \dfrac{N_0}{A}$
QPSK	$\overline{E} = C_0 + C_1 \cdot \left[erfc^{-1}(2 \cdot BER) \right]^2 \cdot \dfrac{N_0}{A}$
16-QAM	$\overline{E} = C_0 + C_1 \cdot 5 \cdot \left[erfc^{-1}\left(\dfrac{2}{3} \cdot BER\right) \right]^2 \cdot \dfrac{N_0}{A}$
64-QAM	$\overline{E} = C_0 + C_1 \cdot \dfrac{35}{3} \cdot \left[erfc^{-1}\left(\dfrac{3}{5} \cdot BER\right) \right]^2 \cdot \dfrac{N_0}{A}$
256-QAM	$\overline{E} = C_0 + C_1 \cdot \dfrac{63}{3} \cdot \left[erfc^{-1}\left(\dfrac{4}{7} \cdot BER\right) \right]^2 \cdot \dfrac{N_0}{A}$

Table 2. Theoretical Average Transmission Energy comparison, for different data rates using different modulation schemes

VI. SIMULATION AND EVALUATION

To show the effectiveness in energy saving for the proposed multirate MAC-PHY scheme, we simulate the proposed multirate scheme based on T-MAC and compare this multirate scheme with S-MAC and T-MAC. The results show that our scheme achieves considerable energy saving. Figure 3 shows the network topology in simulation. For both cases the total energy consumptions are compared among our work and S-MAC as well as T-MAC.
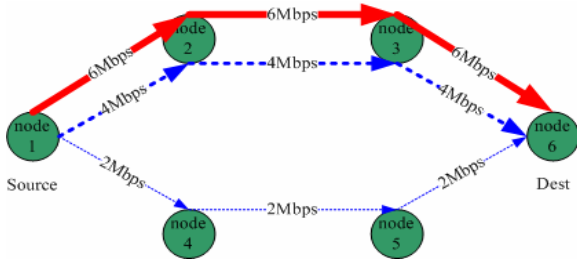

Figure 3. Centralized Traffic (6Mbps) and Distributed Traffic (2Mbps and 4Mbps) Network Model. Node 1 acts as Data Source and node 6 acts as Sink.

The evaluation metrics are defined as the following. The desirable BER is -50db, and the noise power density N0 is J/Hz. The antenna gains together with the channel attenuation factor A is -90db. The frequency bandwidth here is 1 MHz. The modulation scheme look up table is defined as in Table 1. For T-MAC data packets in TinyOS [34], the MAC header is 11 bytes and the payload is 36 bytes. For the control packet such as RTS, ACK, the length is 13 bytes and CTS packet is 15 bytes.. Preamble length is 18 bytes [25]. The TA value of T-MAC used in the simulation is the same as the time of transmitting one RTS packet, while the duty cycle of S-MAC used in the simulation is 30%. The receive power is fixed to 3/4 of the BPSK transmit power, and the sleep power is 0.002, while idle power is 0.9 of the BPSK transmit power [25]. From Equation (1) and (2), we can get that the transmit power for BPSK modulation scheme is 0.036mW, for QPSK is 0.073mW, for 16-QAM is 0.812mW, for 64-QAM is 2.868mW, and for 256-QAM is 6.915mW, with afore mentioned parameters. Traffic load is 64kbytes pure data for every minute.

Figure 4 shows the total energy consumption of the centralized traffic pattern. The proposed multirate MAC achieves 7% more energy efficiency (25mJ for T-MAC,

23.17mJ for proposed multirate scheme) than T-MAC because it transmits data at an acceptable rate, not the highest rate, using a scaled power instead of the max power. The rest of functions are similar to T-MAC.

Figure 5 shows the total energy consumption in distributed traffic pattern. For each route, S-MAC and T-MAC use max-rate-burst-and-sleep mechanism to transmit data. The energy efficiencies of S-MAC and T-MAC are not high in the distributed traffic pattern, since they use fixed power supply and max burst data rate. For the same amount of data, the distributed traffic pattern only balances the traffic load, but does not reduce or increase transmission time for S-MAC or T-MAC. Energy efficiency of the proposed multirate MAC is much better in the distributed traffic pattern, because it can use multiple lower rates to transmit data, with much lower power leading directly to considerable energy savings.
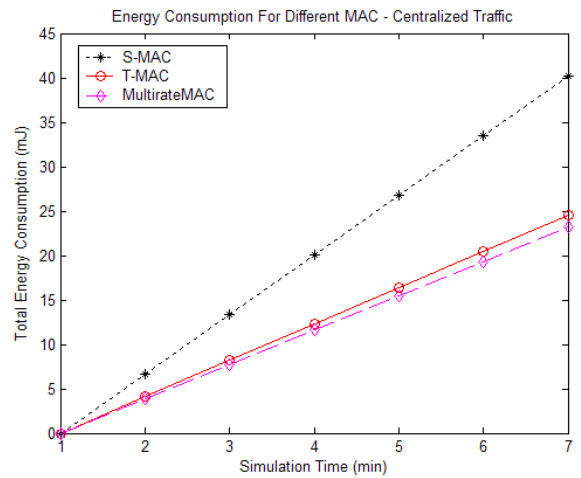

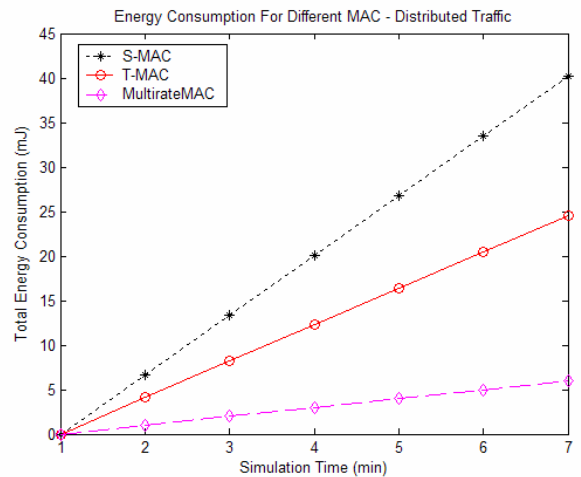Figure 4. Total Energy Consumption of Centralized Traffic

Figure 5. Total Energy Consumption of Distributed Traffic

The proposed multirate MAC consumes 23.17mJ energy in the centralized traffic pattern, while consuming 5.98mJ energy in the distributed traffic pattern. This is because for the same amount of data arriving at the sink node, at the same delay, higher transmission rate is required for centralized traffic

pattern. For the distributed traffic pattern, one high rate traffic route can be divided into several low rate routes, with the same delay of transmission. Multirate MAC achieves considerable energy efficiency in distributed traffic pattern. This is especially suitable for the signal processing applications such as DSC requiring distributed traffic patterns. While the simulation has been conducted for a short period of time as shown in Figure 5, our approach achieves better energy efficiency than T-MAC and S-MAC by a factor of 3.

VII. CONCLUSION

In this paper, we have proposed a novel multirate MAC-PHY scheme, to support DSC type signal processing applications for achieving energy efficiency in WSN. In this approach, MAC calculates the proper transmit power and supplies it to the PHY radio module, according to the desirable BER and the data rates desirable for upper layers. Additionally, we have discussed how to couple the rate and power control between MAC and PHY. Furthermore, MAC layer energy analysis for transmission is performed comprehensively which theoretically shows the advantage of our approach. This proposed approach utilized well-known T-MAC; however, it is not confined to T-MAC because of the independency of rate-power control and the medium access part. Performance and evaluation study based on the simulation results demonstrated that the proposed multirate MAC-PHY scheme achieved considerable energy efficiency, in both centralized traffic pattern and distributed traffic pattern. It achieved more energy efficiency in distributed traffic pattern by a factor of up to three, showing that it is desirable for multirate and distributed signal processing applications in WSN.

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