2014 7th International Symposium on Telecommunications (IST'2014)

DRCP: A Dynamic Resource Control Protocol for Alleviating Congestion

in Wireless Sensor Networks

Nazbanoo Farzaneh , Mohammad Hossein Yaghmaee
IEEE Senior member,
Engineering Department,
Ferdowsi University of Mashhad
Mashhad, IRAN
Emails:{ Farzaneh@stu-mail.um.ac.ir,
yaghmaee@ieee.org}

Mehdi Dehghan TakhtFooladi
Computer Engineering Department
Amirkabir University of Technology
Tehran, IRAN
Email: dehghan@aut.ac.ir

***Abstract*— A Wireless Sensor Network (WSN) is composed of resource-constrained sensors with limited capabilities. Wireless Sensor Networks are subject to more packet loss and congestion. For efficient congestion control, an accurate and timely estimation of resource demands by measuring the network congestion level is necessary. To mitigate congestion, either the available resources have to be increased (resource control) or the source transmission rate should be restricted (traffic control). Most congestion control in WSNs has focused on traffic control. We proposed a Dynamic Resource Control Protocol (DRCP) to control congestion in wireless sensor networks. DRCP utilizes multiple resources to control congestion. DRCP alleviates congestion by controlling transmission power. Simulation results show the performance of the proposed protocol that improves system throughput, and decreases packet dropping, while saving energy.**

Keywords*— *Wireless Sensor Network; Congestion Control; Resource Control; Transmission Power

I. INTRODUCTION

A sensor network consists of elements of communication, sensing, and computing that react to events in an environment [1]. WSN sensors have wide applications in areas such as military, business, health and home applications. Energy conservation, congestion control, reliability in data dissemination, security, and management are among the factors that should be kept in mind in designing WSNs.

Congestion control is one of the main functions of transport control protocols' design. In the case of congestion control, the onset of congestion, its place and time should be detected. A perfect congestion detection method should be energy-efficient and accurate. Upon congestion detection, there are two options to alleviate the congestion: reducing the source rate or increasing the network resource. The problem of congestion in sensor networks remains largely open yet [1, 2]

Most of previous studies on congestion control in WSN control the congestion by throttling the rate at the source and intermediate nodes. Although reducing source rate is effective in some sensor network applications [3, 4], it is inappropriate for some special applications for the following reasons: Firstly, during an emergency or a crisis, the data being generated will be are very important to the application and thus have great value. This should be delivered to sink with higher rate, and thus reducing the source rate during a congested state is undesirable[3]. Secondly, due to elastic availability of resources in WSNs it is easier to use more resources during congestion time to increase network lifetime [3].

In this paper, a resource control protocol is proposed. We call it DRCP for Dynamic Resource Control Protocol for Alleviating Congestion. DRCP tries to adjust the resource provisioning at the congested region. DRCP is used among intermediate nodes in order to offer a node more available resources for transmitting the packets and redirects traffic away from congested areas.

The rest of this paper is organized as follows. In section II a brief review of related work in the WSN transport protocols is presented. The proposed model is explained in section III. In section IV using computer simulation, the performance of the proposed model is evaluated. Finally, section V concludes the paper.

II. RELATED WORKS

To control congestion in WSN, two different approaches are used: traffic control and resource management. The main objective of traffic control approaches is to adapt the source rate base on network congestion level. During past few years, different traffic control protocols have been proposed in WSNs [5-15]. Note that traffic control approaches are not always effective in wireless sensor networks. So for some applications that it is not possible to change the source rate, the resource control schemes are used. CADA [16] computes a node's congestion level by two metrics: buffer occupancy and channel utilization. When congestion occurs, a detour path is built for redirecting traffic to bypass the hotspot region. In [17, 18], two analytical approaches for control congestion in wireless network are presented. These two protocols are applicable in wireless network not for wireless sensor network. In and [19] during periods of congestion the fidelity is increased using "virtual sinks" concept. When congestion is detected virtual sinks redirect the packet using its long radio range to the physical sink. Therefore, the traffic is detoured from congested region. Early Increase/Early Decrease (EIED) [3, 4] is a resource increase and decrease algorithm that adjusts the effective channel capacity to the incoming traffic volume. TARA [4] is a Topology-Aware Resource Adaptation protocol which makes off nodes active in order to change the current topology to alleviate the congestion. The overhead of TARA is high because it should know end to end topology. The work presented in [20] tries to distribute traffic into additional paths to bypass the congestion region. Interface-minimized multipath routing [21] balances the traffic load by discovering zone-disjoint paths. Therefore, the throughput is increased with minimal requirement of localization support. In [22] an online traffic engineering algorithm is presented. The algorithm actions are taken on-demand. The multipath routing is used to alleviate congestion. Idle and under loaded nodes are used during congestion period. A traffic aware routing algorithm (TADR) has been presented in [23]. Each node measures travel cost for its neighbors and selects a neighbor with minimum distance and lower queue length as a next hop.

III. PROBLEM OVERVIEW AND GENERAL APPROACH

A. Problem Formulation

In the proposed protocol we assume that ℕ= {1,2,…,n} sensor nodes are distributed in the network, uniformly. There are a set of links $\mathcal{L}$={1,…,l} that each one is between two nodes *i* and *j* when *j* is within the communication range of *i*. There are *S={1,…,s}* ∈ ℕ source nodes and ℝ=*{1,…d}* sinks in the network. Without loss of generality, in the simulation section we consider only one sink. For each node $i \in \mathbb{N}$, G_i is the set of node *i* neighbors that are in its radio range.

B. Power Consumption Model

To calculate the power consumption in the network, we follow the model used in [24]. Therefore, the power expended in J/s to receive B_r -bit/s in the radio model is given by:

$$E_{rsv}(B_r) = e_t * B_r \tag{1}$$

where e_t (J/bit) is the energy spent per bit in the electronics circuits at the transceiver. The power expended in J/s to transmit B_s-bit/s from one node to the other is given by:

$$E_{snd}(B_s, d) = B_s * (e_d d^{\beta} + e_t) \tag{2}$$

where d is the distance between two nodes, e_d is the energy dissipation for transmitting unit of data over unit of distance, β is the path loss exponent and usually $2 \leq \beta \leq 4$ for the free space and short to medium range radio communication. e_t is the energy dissipated for each bit in transmitter circuitry.

The energy spent by the sensor when it is idle is E_{idle} .

C. General Proposed Approach

In this section we provide an overview of the proposed protocol. For simplicity, we call it DRCP. DRCP is used among intermediate nodes in order to offer a node more of the available resources for transmitting the packets, and to redirect traffic from congested areas. Each node has the capability to decrease or increase its transmission power Increasing transmission power allows a node to discover more neighbors. The overall result is thus a better resource utilization.

When congestion occurs, it becomes important to know that which resource should be increased and by how much to achieve the best result. Increase in one resource may increase or decrease the availability of other resources.

Each node can adjust radio transmit power to vary its communication range from 0 to the maximum transmit range. Adaptive transmission power control recently has received attention in wireless sensor networks and has been studied in the literature in several contexts with different objectives [25, 26]. Thus, it is realistic and suitable for sensor nodes.

For a given node in the network, the algorithm periodically finds the path(s) with minimal cost between that node and every other sink nodes.

D. Resource Availability Measurement and Path Grading

Each node utilizes DRCP algorithm to compute a cost for all of its neighbors, based on the following metrics. Finally, each node elects a neighbor based on a ranking of their costs. Each node collects a neighbor's cost information and computes the path cost for each neighbor j as follows:

$$T_j^i = \alpha Pr_j^i + (1-\alpha)\, C_{ij} \qquad 0 \leq \alpha \leq 1 \tag{3}$$

Where C_{ij} is a communication cost between node *i* and *j*. C_{ij} is calculated as follows:

$$C_{ij} = E_{snd}(B_s, d_{ij}) \tag{4}$$

where d_{ij} is the distance between two nodes *i* and *j*, E_{snd} is the energy consumption for sending data(see (2)). Pr_j is a local cost of node *j*. The local cost of node *j* (Pr_j) is computed as follows:

$$Pr_j = \left(\beta C_n{}^i + (1-\beta) Z_s{}^j\right)^{F_q{}^j} \qquad 0 \leq pr_j \leq 1 \tag{5}$$

where β is a constant coefficient that indicates the importance of each parameter $0 \leq \beta \leq 1$ and $F_q{}^j$ is the free space ratio of node *j's* queue which is calculated as follows:

$$F_q{}^j = \frac{(L_q{}^j - U_q{}^j)}{L_q{}^j} \qquad 0 \leq F_q{}^j \leq 1 \tag{6}$$

where $L_q{}^j$ is the maximum queue length (total space), and $U_q{}^j$ is the number of packets in the queue (used space).

As the queue length increases, the Pr_j^i increases to prevent queue overload.

The node used energy ratio (Z_s) is computed using the following:

$$Z_s = (Z_T - Z_b)/Z_T \qquad 0 \leq Z_s \leq 1 \tag{7}$$

where Z_b and Z_T are respectively, the remaining energy and initial energy of node.

The node drop status $C_n{}^i$ shows the node drop probability of a given node. $C_n{}^i$ is obtained by combining the node congestion index (I^i) and MAC discard probability (p_d^i) which shows the probability of dropping packet in a node. $C_n{}^i$ is computed as follows:

$$C_n{}^i = I^i + \left(1 - I^i\right) * p_d^i = I^i + p_d^i - \left(I^i * p_d^i\right) \quad (8)$$

Where I^i is a node congestion index and p_d^i is a MAC packet discard probability of node i that are computed as follows:

I^i is computed using the Average Loss Interval (ALI) [27] method to calculate packet loss probability.. Suppose that l_k (k =1,..,8) be the number of packets in the k^{th} most recent loss interval. n is the number of intervals. Two variables l and l_{new} are used as follows [27]:

$$l = \frac{\sum_{j=1}^{n} w_j l_j}{\sum_{j=1}^{n} w_i} \quad (9)$$

$$l_{new} = \frac{\sum_{j=0}^{n} w_{j+} l_j}{\sum_{j=1}^{n} w_i} \quad (10)$$

For weights equal to:

$$w_j = 1\,, 1 \le j \le n/2 \quad ; \qquad w_j = 1 - \frac{j - n/2}{n/2 + 1}, \quad n/2 < j \le n$$

Therefore the drop percent (congestion index) I^i is defined as follows:

$$I^i = \frac{1}{max(l, l_{new})} \quad (11)$$

p_d^i, is the ratio of generated packets that are not successfully transmitted. p_d^i is the probability of dropping packet either due to channel access failure, or because of collision. Following [28], we can compute the MAC packet discard probability:

$$p_d = p_c^{R+1} + p_f \frac{1 - p_c^{R+1}}{1 - p_c} \quad (12)$$

where p_f and p_c are channel access failure probability and collision probability respectively, R is the maximum number of retransmission attempts at the MAC layer.

Using the history of the node status, $C_n{}^i$ can be computed by using a weighted average method in which each computed $C_n{}^i$ over past T period of time, carries different significance as follows:

$$C_n{}^i(t) = \vartheta \times C_n{}^i(t) + \sum_{j=1}^{T} (1 - \vartheta)^j \times C_n{}^i(t - j) \quad (13)$$
$$t \ge 1 \quad , \quad 0 \le \vartheta \le 1$$

where t demonstrates the backward step to the past history. The parameter ϑ controls the effect of the current drop percentage. Since both I^i and p_d^i are in [0,1] intervals, the $C_n{}^i$ is also in [0,1] interval. The higher the value of $C_n{}^i$ the higher the drop probability and the congestion level of the node.

All nodes broadcast their local node cost (Pr_i) and their minimum cost to the sink, periodically. Each node collects a neighbor's cost information and computes the path cost for each neighbor j. Thus, node i computes its least cost path to sink s as follow:

$$P_{is} = \min_{j \in G_i^r}\{T_j^i + P_{js}\} \quad (14)$$

For each node $i \in N$, G_i^r is the set of node i 's neighbors that are in its radio range r. Each node j periodically sends its node price (T_j^i) and its transmission cost to sink s (P_{is}) to its neighbors.

E. Resource Increment Procedure

As soon as the hot spot node detects that its congestion level is above some upper threshold, it needs to quickly increase its resources. There are three congestion thresholds, inc_{th}, pre_{th}^{inc} and dec_{th} in this system which determine whether the resource decrement or increment will be started or not. The first two are used to specify the color of each node as follows:

GREEN: $min_{j \epsilon G^i}\{T_j^i\} \le pre_{th}^{inc}$ (): No congestion problem.

YELLOW: ($pre_{th}^{inc} < \min_{j \epsilon G^i}\{T_j^i\} \le inc_{th}$): Congestion is about to occur. Thus the node starts to gather extra information to run the transmission power enhancement procedure.

RED: ($min_{j \epsilon G^i}\{T_j^i\} > inc_{th}.$): The transmission power enhancement procedure is started.

BLACK: A node is unable to enhance its resources. Thus it stops to accept any packets from its neighbors to save its current resources.

The maximum radio range increment is determined based on node remaining energy and the MAC discard probability. Let E_r and $E_{r'}$ be the communication energy consumption with radio range r (current radio range) and r' (new radio range), respectively. E_r and $E_{r'}$ are defined as follows:

$$E_r = e_t r^{\beta} \quad (15)$$

$$E_{r'} = e_t r'^{\beta} \quad (16)$$

To have $\Delta E = \left(E_{r'} - E_r\right) \le \gamma$ (γ is the upper bound of the difference of energy consumption with current and new radio range), the upper bound of r' is obtained as (17), using (15) and (16):

$$r' \le \sqrt[\beta]{\frac{E_r - \gamma}{e_t}} \qquad \gamma = \psi * E_{cur} \qquad 0 \le \psi \le 1 \quad (17)$$

The value of γ is significant as it strongly affects the energy conservation. For instance, to save energy, γ can be determined based on the remaining energy (E_{cur}) at a node. Let us to describe the transmission power increment procedure by an example. Consider the example shown in Fig.1.

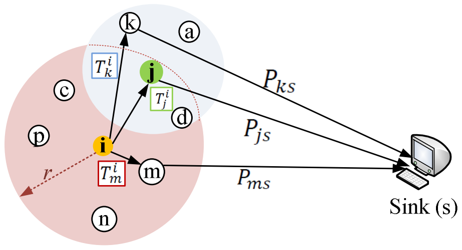

Fig. 1. An example to explain transmission power increment

Assume node i has the radio range r. The list of node i*'s* neighbors is given by $G_i^r = \{c, d, p, n, m\}$. Suppose node m is the current next hop of node i so it has the minimum path cost to the sink s through m (P_{is}). When the color of node i is YELLOW, it starts to gather extra information in order to use it for resource control procedure if needed. When node i*'s* color changes to YELLOW, a CO bit (Congestion is Occurring) is set in the packet's header to notify the neighbors. Furthermore, it puts its maximum allowed transmission power r' (see (17)) in the packet. This packet is received by all of its neighbors. They start to select a proper node to suggest it to node *i*. For example when node *j* receives a packet which its "CO" bit is set, it selects its minimum cost neighbor in terms of i (for example k) and sends the k*'s* costs to node *i in* the next round. The suggested neighbor k should have the following characteristics:

- The distance between i and k should be less than r' ($d_{ik} \leq r'$)
- The path cost (to the sink *s*) of node k for node i should be less than the path cost (to the sink *s*) of node j for node i ($T_k^i + P_{ks} < T_j^i + P_{js}$)
- The node color of node k should not be "BLACK"
- k should not be in the node *i's* current neighbor list ($k \notin G_r^i$)

Node *i* receives all suggested nodes from its neighbors and updates its suggested list to use it when appropriate. When the color of node *i* changes to RED it searches its suggested list to elect a new neighbor as a next hop. Thus node i needs to increase its transmission power to cover the new neighbor. Suppose k is the minimum cost node of the suggested list and m is the current minimum cost node of node *i*, if the following conditions occurs, then the node i does not increase its transmission power:

If the minimum cost of the suggested list is greater than its current minimum cost node cost. ($T_k^i + P_{ks} > T_m^i + P_{ms}$)

Increasing radio range from r to r' will increase the MAC discard probability from P_d^N to $P_d^{N+\zeta}$ where N is the number of neighbors with radio range r and $N + \zeta$ is the number of neighbors with radio range r' (ζ can be estimated through nodes distribution function). Let χ be the upper bound of the allowable dropped packets in MAC layer with regard to network performance. If $P_d^{N+\zeta}$ is greater than χ, the radio range is not changed. If $P_d^{N+\zeta}$ is less than χ then the radio range will change from r to *r'*. Although the $\chi = 0$ is desirable, it is not possible with regard to the characteristics of WSNs. The value of χ is related to network characteristics such as number of nodes, network density, etc. Thus if the following condition should be satisfied

$$r' \leq \left(\sqrt[\beta]{\frac{E_r - \gamma}{e_t}} \,\middle|\, \langle P_d^{N+\zeta} < \chi \rangle \right) \qquad 0 \leq \chi \leq 1 \tag{18}$$

Higher transmission power allows higher communication coverage and more energy consumption. Once a node has limited energy, the transmission power should not be increased in order to save energy. The value of β is set to 2.

In the following cases, the transmission power increment is canceled:

- If k is not able to change the i*'s* color from RED and
- If $(T_m^i + P_{ms}) - (T_k^i + P_{ks})$ is small when compared to the increase in energy consumption and MAC drop probability

When node *i* is not able to increase its radio range and not find any appreciate neighbor, it changes its color from RED to BLACK and informs this fact to the nodes around it. Neighboring nodes remove the related node from their active neighbor list. Thus, the node is not selected as a next hop by other nodes in subsequent rounds. A BLACK node just send its remaining packets and participates in exchanging cost information phase until its color changes from BLACK. When a BLACK node changes its color from BALCK and becomes available again, the neighbor nodes are informed accordingly. When a source realizes that all of its neighbors are BLACK, it should start the traffic control procedure to reduce its sending rate.

F. Resources Decrement Procedure

As congestion decreases, the resource decrement procedure is started to save available resources. To perform this, each node i evaluates its neighbors' costs, periodically. If the maximum cost is less than the threshold, dec_{th}, the node decreases its transmission power to avoid energy consumption. Radio range reduction satisfies the following conditions:

$$max_j\{T_j^i\} \leq dec_{th} \text{ and } d_{ik} \leq r^{i''}$$

k: selected neighbor with minimum T_k^i , $r^{i''}$ is less than current r^i (19)

After reducing transmission power, if a node encounters a change in its neighbor list (due to the exit of a node), it should send an update message to tell them that they have been exited from its neighbors list.

G. Congestion Thresholds

The three congestion thresholds are periodically adapted based on the congestion level. We used a EWMA based method to calculate an average of minimum cost and maximum cost over some period of time as follows:

$$Cmin_{avg}^i(t) = \delta Cmin_{avg}^i(t-1) + (1-\delta) \min_{j \in G^i}\{T_j^i(t)\}$$

$$Cmax_{avg}^i(t) = \mu Cmax_{avg}^i(t-1) + (1-\mu) \max_{j \in G^i}\{T_j^i(t)\} \tag{20}$$

$$0 \leq \mu, \delta \leq 1$$

$$dec_{th}(t) = dec_{th}(t-1) * \left(\frac{Cmac_{avg}^i(t-1)}{Cmax_{avg}^i(t)} \right) \tag{21}$$

$$inc_{th}(t) = inc_{th}(t-1) * \left(\frac{Cmin_{avg}^i(t-1)}{Cmin_{avg}^i(t)} \right) \tag{22}$$

where $T_j^i(t)$ is the total cost of node i to select node j. δ and μ are weights which can be set using simulation, or by experimentation.

When the congestion level is increased, the minimum and maximum costs are increased too. As a result the radio range increment probability is grown and radio range decrement probability is reduced. By using simulation and experimentation, an initial value of dec_{th} and inc_{th} is defined based on the first cost table as follows:

$$\begin{aligned} dec_{th} &= avg(\min_{j\epsilon G^i}\{T_j^i\}\ , \max_{k\epsilon G^i}\{T_k^i\}) \\ inc_{th} &= \max_{k\epsilon G^i}\{T_k^i\} \end{aligned} \qquad (23)$$

where $min_{j\epsilon G^i}\{T_j^i\}$ $(max_{k\epsilon G^i}\{T_k^i\})$ is the minimum (maximum) cost of node i to select node j as its next hop. The pre_{th}^{inc} parameter can be calculated as follows:

$$pre_{th}^{inc} = inc_{th} * \theta_t \qquad 0 < \theta_t\, , \theta_d < 1 \qquad (24)$$

IV. SIMULATION RESULTS

In this section, we use a simulation study to evaluate the performance of the proposed protocol under different scenarios. 100 nodes were deployed in 400×400 m^2 grid using OPNET simulator [29]. Each simulation is run 10 times and then the results are averaged. To simulate a real environment, the values for the power consumption parameters at the intermediate nodes were chosen as the same for an 802.15.4-compliant RF transceiver CC2430 [30].

The proposed protocol is implemented, and compared with resource control based scheme named TADR [23]. TADR is it similar to our approach in that it controls congestion by using resource control method.

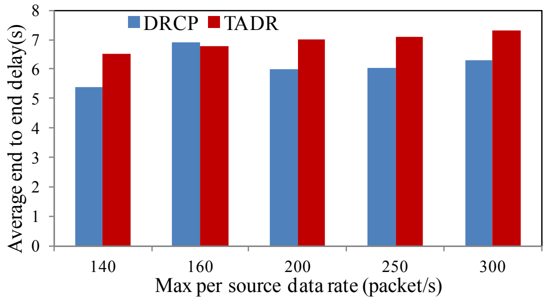

Fig. 2. Average end to end delay

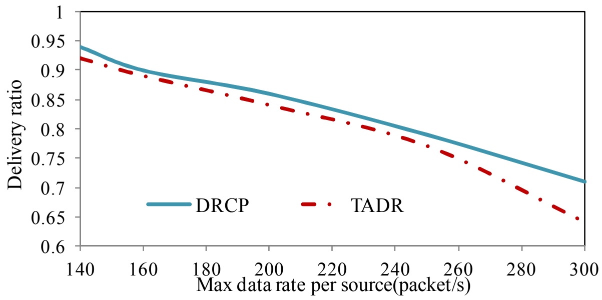

Fig. 3. Delivery ratio

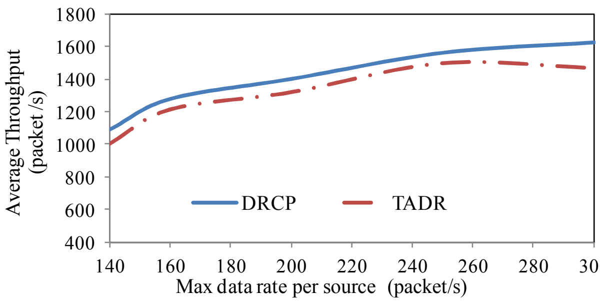

Fig. 4. Average Network throughput

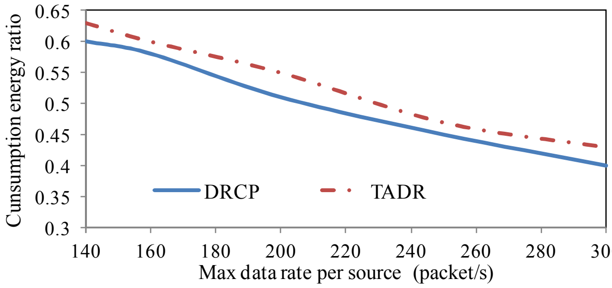

Fig. 5. Fig 5: Network consumed energy

Fig. 2 shows average end-to-end delay in periodic data generation scenarios. The notable issue is that in DRCP protocol, cost is the sum of transmitting costs of all nodes along the path, while TADR considers just the next hop cost. TADR cannot estimate the sum of queuing delays of the path. TADR just pays attention to the queue length of the next hop neighbors. Therefore, the estimation of the end-to-end delay and loss are not possible in TADR.

In this paper, we consider a realistic MAC layer model to represent the contention between nodes in the network. Thus packet loss occurred because of MAC layer contention and queue overflow. As can be observed in Fig. 3 (delivery), the number of received packets in DRCP is higher than TADR which is a result of using the nodes with lower drop probabilities and higher energy.

In the proposed protocol, cost is the sum of transmitting costs of all nodes along the path. If node i is unable to find a path with a reasonable cost, then it attempts to find more neighbors with a higher radio range. Higher radio range will increase the number of neighbors. Thus, a node possesses more options to obtain a path with suitable cost. Since the nodes' local cost contains MAC packet discard probability, the nodes with higher local cost have lower chance to be selected as the next hop. Consequently, by increasing the transmission power, the probability of successful end to end data delivery is improved.

In sever congestion, the resource availability is decreased and packets are dropped either due to collision or due to buffer overflow. As a result the delivery ratio is decreased. As shown in Fig. 3 the delivery ratio of DRCP and TADR are decreased in high traffic rate due to lack of resources.

Fig. 4 displays the throughput of all protocols. Network throughput is the average rate of successful packet delivery. DRCP and TADR are not reducing sending rate during congestion.

Fig. 5 shows the nodes energy consumption. The proposed protocol is an energy-efficient method that avoid congestion with an acceptable rate of energy consumption. The network lifetime is the time until the first node dies. The DRCP protocol transmit more packets along the network than TADR. As a result, it is more appropriate and fairer to consider that the ratio of energy consumption to the transmitted packets.

V. CONCLUSION

In this paper we presented a resource aware congestion control protocol that alleviates congestion by controlling transmission power. A wireless sensor network typically involves many resources. When congestion occurs in a WSN, it is essential to quickly determine which resource(s) should be increased and by how much to best alleviate the problem. The ultimate goal of the protocol is to utilize available resources with low energy consumption, which will, in turn, lead to congestion control. Several potential metrics are introduced that confirms the congestion level and available resources along the path from source to sink. Increasing the transmission power offers more neighbor nodes that can serve as the next hop, and results in a higher channel capacity. The congestion thresholds are periodically adapted based on the congestion level that makes it capable of detecting congestion more accurately.

REFERENCES

[1] K. Sohraby, D. Minoli, and T. Znati, Wireless Sensor Networks: Technology, Protocols, and Applications. Wiley-Interscience, 2007.

[2] A. W. Holger Karl, "Protocols and Architectures for Wireless Sensor Networks," Networks 2005.

[3] K. Jaewon, Y. Zhang, and B. Nath, "Analysis of Resource Increase and Decrease Algorithm in Wireless Sensor Networks," in Computers and Communications, 2006. ISCC '06. Proceedings. 11th IEEE Symposium on, 2006, pp. 585-590.

[4] K. Jaewon, Y. Zhang, and B. Nath, "TARA: Topology-Aware Resource Adaptation to Alleviate Congestion in Sensor Networks," Parallel and Distributed Systems, IEEE Transactions on, vol. 18, pp. 919-931, 2007.

[5] C. Wang, B. Li, K. Sohraby, M. Daneshmand, and Y. Hu, "Upstream congestion control in wireless sensor networks through cross-layer optimization," Selected Areas in Communications, IEEE Journal on, vol. 25, pp. 786-795, 2007.

[6] M. H. Yaghmaee and D. A. Adjeroh, "Priority-based rate control for service differentiation and congestion control in wireless multimedia sensor networks," Comput. Netw., vol. 53, pp. 1798-1811, 2009.

[7] O. B. Akan and I. F. Akyildiz, "Event-to-sink reliable transport in wireless sensor networks," Networking, IEEE/ACM Transactions on, vol. 13, pp. 1003-1016, 2005.

[8] J. Paek and R. Govindan, "RCRT: Rate-controlled reliable transport protocol for wireless sensor networks," ACM Trans. Sen. Netw., vol. 7, pp. 1-45, 2010.

[9] M. H. Y. Moghaddam and D. Adjeroh, "A Novel Congestion Control Protocol for Vital Signs Monitoring in Wireless Biomedical Sensor Networks," in Wireless Communications and Networking Conference (WCNC), 2010 IEEE, 2010, pp. 1-6.

[10] A.A. Rezaee, M. H. Yaghmaee, A. M. Rahmani, and A. H. Mohajerzadeh, "HOCA: Healthcare Aware Optimized Congestion Avoidance and control protocol for wireless sensor networks," Journal of Network and Computer Applications, vol. 37, pp. 216-228, 2014.

[11] M. Samiullah, S. M. Abdullah, A. F. M. I. H. Bappi, and S. Anwar, "Queue management based congestion control in wireless body sensor network," in Informatics, Electronics & Vision (ICIEV), 2012 International Conference on, 2012, pp. 493-496.

[12] M. Yaghmaee, N. Bahalgardi, and D. Adjeroh, "A Prioritization Based Congestion Control Protocol for Healthcare Monitoring Application in Wireless Sensor Networks," Wireless Personal Communications, vol. 72, pp. 2605-2631, 2013/10/01 2013.

[13] S. Misra, V. Tiwari, and M. Obaidat, "Lacas: learning automata-based congestion avoidance scheme for healthcare wireless sensor networks," Selected Areas in Communications, IEEE Journal on, vol. 27, pp. 466-479, 2009.

[14] N. Farzaneh and M. Yaghmaee, "Joint Active Queue Management and Congestion Control Protocol for Healthcare Applications in Wireless Body Sensor Networks," in Toward Useful Services for Elderly and People with Disabilities. vol. 6719, B. Abdulrazak, S. Giroux, B. Bouchard, H. Pigot, and M. Mokhtari, Eds., ed: Springer Berlin Heidelberg, 2011, pp. 88-95.

[15] M. M. Alam and C. S. Hong, "CRRT: Congestion-Aware and Rate-Controlled Reliable Transport in Wireless Sensor Networks," IEICE Transactions on Communications, vol. E92.B, pp. 184-189, 2009.

[16] J.-m. C. Wei-wei FANG, Lei SHU, Tian-shu CHU, De-pei QIAN, "Congestion avoidance, detection and alleviation in wireless sensor networks," Journal of Zhejiang University, vol. 11, pp. 63-73, 2010.

[17] X. Yufang and E. M. Yeh, "Node-Based Optimal Power Control, Routing, and Congestion Control in Wireless Networks," Information Theory, IEEE Transactions on, vol. 54, pp. 4081-4106, 2008.

[18] N. H. Tran, H. Choong Seon, and L. Sungwon, "Joint Congestion Control and Power Control With Outage Constraint in Wireless Multihop Networks," Vehicular Technology, IEEE Transactions on, vol. 61, pp. 889-894, 2012.

[19] C.-Y. Wan, S. B. Eisenman, A. T. Campbell, and J. Crowcroft, "Overload traffic management for sensor networks," ACM Trans. Sen. Netw., vol. 3, p. 18, 2007.

[20] J. Kang, Y. Zhang, and B. Nath, "An optimal resource control scheme under fidelity and energy constraints in sensor networks," Wirel. Netw., vol. 15, pp. 497-512, 2009.

[21] T. Jenn-Yue, H. Yajun, and T. Chen-Khong, "Interference-Minimized Multipath Routing with Congestion Control in Wireless Sensor Network for High-Rate Streaming," Mobile Computing, IEEE Transactions on, vol. 7, pp. 1124-1137, 2008.

[22] M. A. RAZZAQUE, C. S. HONG, and S. LEE, "Autonomous Traffic Engineering for Boosting Application Fidelity," IEICE Transaction on Communications, vol. E93-B, pp. 2990-3003, 2010.

[23] R. Fengyuan, H. Tao, S. Das, and L. Chuang, "Traffic-Aware Dynamic Routing to Alleviate Congestion in Wireless Sensor Networks," Parallel and Distributed Systems, IEEE Transactions on, vol. 22, pp. 1585-1599, 2011.

[24] W. B. Heinzelman, A. P. Chandrakasan, and H. Balakrishnan, "An application-specific protocol architecture for wireless microsensor networks," Wireless Communications, IEEE Transactions on, vol. 1, pp. 660-670, 2002.

[25] X. Shuo, A. Dhamdhere, V. Sivaraman, and A. Burdett, "Transmission Power Control in Body Area Sensor Networks for Healthcare Monitoring," Selected Areas in Communications, IEEE Journal on, vol. 27, pp. 37-48, 2009.

[26] Z. Zhiwei, Z. Xinming, S. Peng, and L. Pengxi, "A Transmission Power Control MAC Protocol for Wireless Sensor Networks," in Networking, 2007. ICN '07. Sixth International Conference on, 2007, pp. 5-5.

[27] S. Floyd, M. Handley, J. Padhye, #246, and r. Widmer, "Equation-based congestion control for unicast applications," SIGCOMM Comput. Commun. Rev., vol. 30, pp. 43-56, 2000.

[28] A. Faridi, M. R. Palattella, A. Lozano, M. Dohler, G. Boggia, L. A. Grieco, and P. Camarda, "Comprehensive Evaluation of the IEEE 802.15.4 MAC Layer Performance With Retransmissions," Vehicular Technology, IEEE Transactions on, vol. 59, pp. 3917-3932, 2010.

[29] http://www.opnet.com.

[30] T. Instruments, "CC2430 Preliminary Data Sheet rev. 2.1," ed, p. 211.