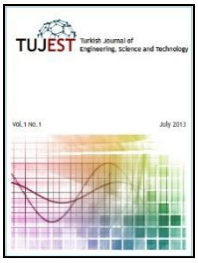
Turkish Journal of Engineering, Science and Technology 01 (2014) 12-22

TUJEST

Turkish Journal of Engineering, Science and Technology

journal homepage: www.tujest.com



A Survey of Congestion Control Protocols Providing Energy Conservation In Wireless Sensor Networks

Ayhan Kiraz[a], **Murat Çakıroğlu**[b,*]

[a] *Technical Education Faculty, Electronics & Computer Department, Sakarya University, Sakarya,TURKEY*

b Technology Faculty, Mechatronic Engineering Department, Sakarya University, Sakarya, TURKEY

Article Info

Article history:
Received December 11, 2013
Accepted December 25, 2013
Available online February 13, 2014

Keywords:
Transport Layer,
Wireless Sensor,
Congestion,
Congestion Control,
Energy Saving

Abstract

Energy consumption is very important in recent years. Since, more and more energy is needed with increasing technology. In this case, energy-saving requirement increases more and more every day. Wireless sensor networks are composed of battery limited sensor nodes that can sense the physical information, process the sensed information, and report it to the sink. WSNs have wide range application areas because they have a lot of advantages such easy deployment, self-organization, scalability and low maintenance. But, they have some big challenges such as energy restriction and packet losses. Congestion is the one of the essential problems of WSNs since it increases energy consumption of sensor nodes due to packet drops and retransmissions of packets. Most of WSN applications require congestion controls to regulate traffic and prevent packet losses. A lot of protocols have been proposed to deal with congestion problem in WSNs. In this paper, we have evaluated and summarized the representative WSN congestion protocols that provide energy conservation for the researchers who are newly on congestion. We have selected popular congestion control protocols and compared them in terms of some criterias.

1. Introduction

Energy demand is expected to be in the near future. Therefore, energy conservation is great importance in our lives. Large numbers of studies have been done on this subject. Some of these are biological waste utilization [1][2][3][4][5], using solar energy [6][7][8][9], wind energy generation [10], thermal energy[11] and energy saving of power battery [12][13]. WSNs consist of several wireless sensor nodes, which include small-integrated sensors, a microcontroller, a RF transceiver, and a battery. The size of these networks is mainly determined by the requirements of the application. The task of each sensor node is to collect the different physical information such as humidity, temperature, pressure and sound [14] from the target environment and is to forward to the base station in an ad-hoc manner. They can be used in wide range applications such as energy efficient data applications [15], indoor scenarios [16], tracking fast moving targets applications [17] and human boy applications [18]. In Fig 1, a typical wireless sensor network system can be seen. The properties of WSNs such as easy deployment, self-organization, scalability, low maintenance make them more attractive than traditional network systems. Besides these advantages, WSNs have some challenges such as energy restriction, packet losses, and security vulnerability. The packet losses increase energy consumption of the sensor nodes and delivery time of information. Therefore, it is one of the biggest problems of WSNs. The packet losses in WSNs generally are due to high error rate of communication link and congestion. Congestion is a situation in which is too much the data traffic at a node. Thus, the network slows down or starts loosing data. Congestion is occurred by two reasons. The first reason is the packet arrival

*Corresponding Author:
M. Cakiroglu, E-mail: muratc@sakarya.edu.tr

time that is more than service rate. The second reason is channel contention time, and high bit error rate. Congestion can cause buffer overloading problem and packet losses. Therefore, it increases energy consumption of the sensor nodes. Additionally, congestion can reduce link usage and increases packet arrival time. So, congestion is one of the crucial problems to be solved in WSNs.

Recently, the researchers focus on congestion in WSNs. In the literature, there are various studies about congestion problem [19]. But, to the best of our knowledge, there is no survey paper directly summarizes the congestion protocols and methods. Therefore, in this paper, we aim to evaluate and summarize the existing WSN congestion protocols for the researchers who are newly on congestion. We have selected representative congestion control protocols and compared them in terms of some criteria such as energy efficiency and packet service time.

2. Related work

In literature, it is proposed three methods as known congestion detection, notification, and mitigation to deal with congestion problem [19]. In the first method, congestion detection is mostly performed according to the queue occupancy [20][21], packet arrival time [22], and packet arrival ratio [23] parameters. In the second method, when a node detects the congestion, it notifies the other sensor nodes with congestion notification (CN) bit [24]. CN is propagated by intermediate nodes to the sink. After the sink received a packet including CN bit from the nodes, it understands whether congestion will occur in next period [19]. In the third method, congestion mitigation and avoidance is achieved by monitoring the network traffic. Monitoring of network traffic arranges the sending rate of intermediate or source nodes. This method is useful to protect network resources. Traffic monitoring can be realized by end to end or hop by hop manner. In the end to end control method, source nodes should adjust the sending rate. Therefore, its response time is long, and relies highly on Round Trip Time (RTT) [19]. The hop by hop congestion control has faster response time than end to end control. But, it is difficult to adjust the packet sending rate at intermediate nodes, since the packet forwarding rate is dependent on the MAC protocol.

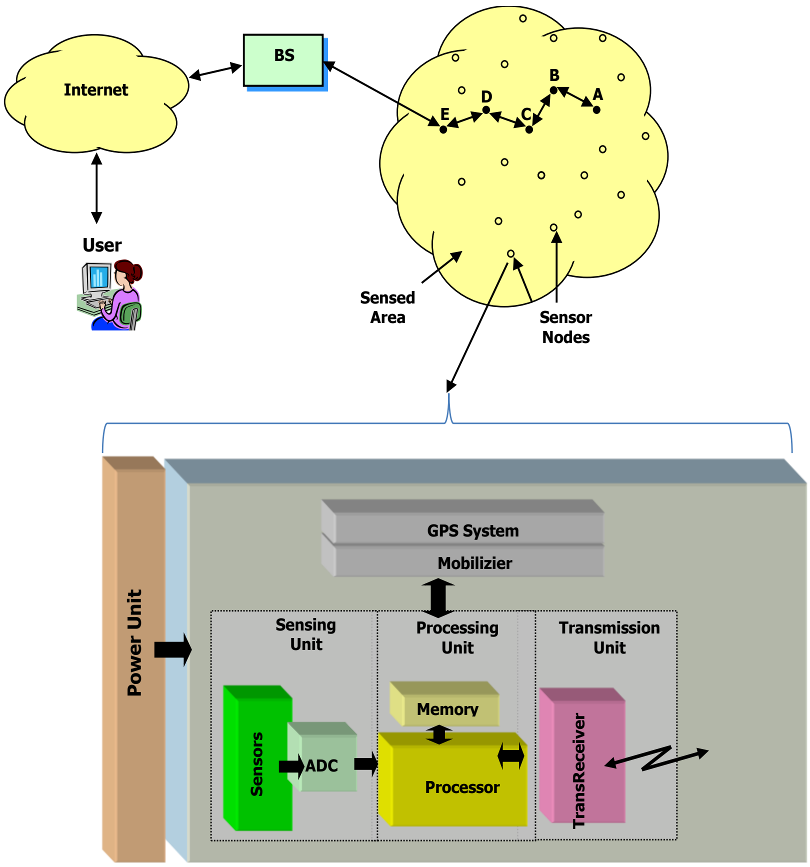


Fig1.Wireless Sensor Network and components of sensor node

The rest of the paper is organized as described below. Congestion control methods will be clarified in Section 2. Congestion protocol design factors are introduced in Section 3. In Section 4, popular congestion control protocols for WSNs are described. In Section 5, Comparison of the selected congestion protocols is presented. The paper is concluded by Section 6.

3. Congestion control design factors

WSNs should be designed according to the requirements of Quality of Service (QoS) in many applications. Since congestion control protocols are closely related to QoS parameters such as reliability, end-to-end delay and etc. They are so necessary for QoS-aware applications [25].

In this chapter, we discuss the design factors of a congestion control protocol such as Quality of service, energy efficiency, reliability and fairness [26].

3.1. Energy efficiency

Energy conservation is the most important design rule in WSNs. So, the designed protocols for WSNs should be energy-aware. A congestion control protocol detects the congestion and reduces the packet loss. Thus, it can be contribute the energy conservation. But, it should take into account the control messages overhead

3.2. Reliability

In some critical WSN applications, reliability may be so important. Some applications require not only reliable but also timely delivery of data [27]. Namely, It may be required that each packet reach to target nodes. The reliability is classified into two categories such as event and packet reliability. Packet losses are so important in packet reliability based applications. But, in event reliability based applications, it is only required successful event detection [19].

3.3. Quality of Service (QoS)

Bandwidth, packet delay and packet loss rate are some of the well-known QoS metrics. Many wireless sensor network applications are closely related to these QoS metrics. For examples, in a target tracking application, sensor nodes should transmit high bandwidth data such as real-time images or videos. In a delay-sensitive application such as health monitoring application, it may be required the timely delivery of sensory data. A congestion protocol should be designed paying attention these requirements [28].

3.4. Fairness

Wireless sensor nodes are usually scattered to the monitoring area. In the most WSN application the sensory data should be carried from away nodes to sink by many-to-one communication model. This model may be caused to the bottlenecks and so, it is highly susceptible to congestion. Therefore, the congestion protocols are so important for supplying fair bandwidth allocation between sensor nodes [5].

4. Congestion control protocols for wireless sensor networks

Congestion is a big problem in WSNs, since it is related to energy efficiency. Congestion occurs when too much network traffic, and it causes the increase of packet loss and the decrease of channel capacity. So, congestion increases the energy consumption of sensor nodes. Therefore, recently, the researchers focus on congestion control mechanisms in WSNs.

In the literature, congestion control protocols are divided into two main categories such as hop by hop and end to end protocols according to the method of operation. In Fig 2, hop by hop and end to end congestion control protocols can be seen. In this paper, we conduct a brief literature survey on congestion control protocols in WSNs.

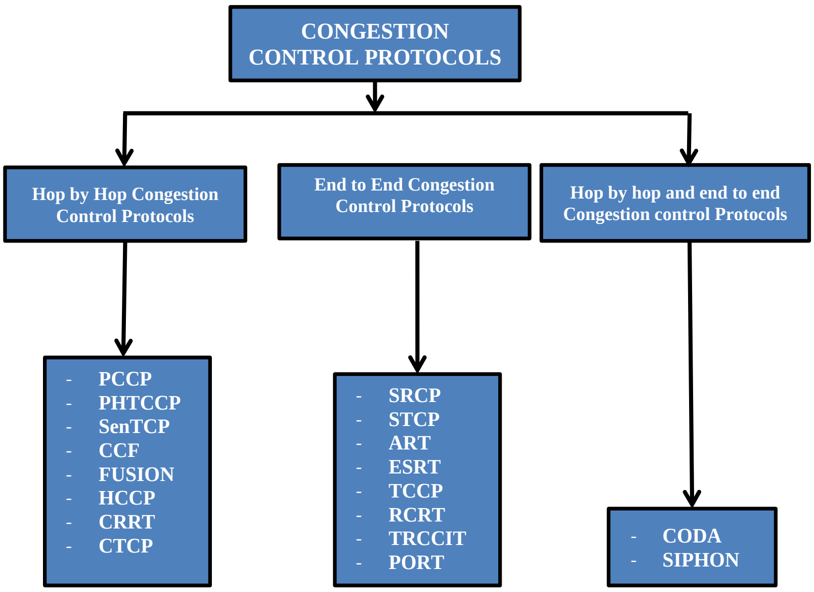


Fig2. Congestion control protocols.

4.1. Hop by hop Congestion control Protocols

In this section, we will discuss about congestion control protocols that use hop by hop control method. We will briefly describe the hop by hop protocols such as PCCP, PHTCCP, SenTCP, CCF, Fusion, HCCP, CRRT and CTCP.

4.1.1. PCCP

PCCP (Priority-based Congestion Control Protocol) developed by Wang, Sohraby, Lawrence, Li and Hu [29] in 2006. PCCP is designed as an upstream hop by hop congestion control protocol for WSN. Priority of a node in PCCP is dependent on application and can be updated by the sink node. Firstly, PCCP uses packet arrival time to determine congestion level. This metric also gives an idea about the occurrence of packet loss. Secondly, PCCP uses implicit congestion notification information [19] and avoids from unnecessary control messages. Thirdly, PCCP provides to control the priority rate depending on the congestion degree. Namely, it doesn't require any additional control messages. Consequently, PCCP uses a priority based rate regulation algorithm to assure flexible fairness and throughput.

4.1.2. PHTCCP

PHTCCP (Prioritized Heterogeneous Traffic-Oriented Congestion Control Protocol) [30] developed by Monowar, Rahman, Pathan, and Hong in 2008. PHTCCP is a congestion control protocol that uses hop by hop method. When congestion occurs, it adjusts transmission rate. It allows using efficient link capacity even if some nodes are in the passive or sleep mode. PHTCC uses the WFQ (Weighted Fair Queuing, WFQ) for packet scheduling. WFQ is a data packet scheduling technique allowing different scheduling priorities to statistically multiplexed data flows.

PHTCCP uses a parameter called to Packet Service Ratio R(i) to detect the congestion level. **R(i)** can be calculated by dividing Packet Service Rate **(R x I / S)** and packet scheduling rate **(R x I / Sch)**. Each node forwards some information to the other nodes in the packet headers. This information is the packet scheduling rate, the total number of child nodes, number of child nodes that are active during specified time (t), and the average queue length of its active child nodes. Thus, all nodes are aware of congestion notification information. PHTCCP provides desired throughput for diverse data according to the priority specified by the base station, high link utilization, moderate queue length to reduce packet loss, relatively low packet drop rate.

4.1.3. SenTCP

SenTCP [31] designed by Wang, Sohraby and Li in 2005. It uses hop by hop control method for upstream data traffic. SenTCP measures the congestion level in every intermediate sensor node by the help of packet arrival time, packet inter-arrival time and buffer status parameters. When a node detects the congestion, it sends a packet to its neighbor nodes. In the packet, there is congestion level information and buffer status indicator. In SenTCP, when a node receives a congestion message, it arranges own packet sending rate. So, network congestion status is regulated immediately and packet dropping is decreased. SenTCP provides the congestion control, but it has not any reliability mechanism.

4.1.4. CCF Protocol

CCF [22] (Congestion Control and Fairness) protocol has designed by Ee and Bajcsy in 2004. It provides hop by hop upstream congestion control [32]. CCF protocol determines congestion by calculating number of downstream nodes, average sending rate, data packet generation rate and downstream propagation rate. When congestion occurs, congestion information must be forwarded to downstream nodes and so, the nodes decrease their sending rate [32]. For supplying fairness, CCF uses two methods such as sub-packet queues and sub-tree size. In sub-packet queues, every node uses an indexed queue for each child nodes. CCF distributes the control message in data packets. In this mechanism, additional packets are not needed. CCF uses two scheduling algorithms such as probabilistic selection (PS) and Epoch based proportional election (EPS) [28] to improve fairness. These algorithms may increase fairness among sensor nodes besides decrease packet delivery latency.

4.1.5. Fusion Protocol

Fusion [21] protocol has designed by Hull, Jamieson, Balakrishnan in 2004 and it provides upstream hop by hop congestion control. It has three methods such as hop by hop control, source traffic limiting, and giving priority to MAC protocol. In the first method, congestion is detected by controlling queue status and channel load techniques. Congestion bit in the packet header is set and congestion notification information is sent to other neighbor nodes. When neighbor nodes receive congestion information packet, they give up sending packets. The disadvantage of rate adjustment method is to negatively affect radio link utilization and fairness. In second technique, nodes use the resources on an equal basis to supply fairness. In third technique, if a node is under congestion, it drains output queue to improve the congestion by allocating prioritized access to the physical channel [32]. Fusion has congestion control but it has no reliability mechanism.

4.1.6. HCCP

HCCP [33] (Hybrid Congestion Control Protocol in Wireless Sensor Networks) designed by Sheu, Hu and Chang in 2009. HCCP is a hop by hop congestion control method. It is a hybrid congestion protocol that considers both the packets delivery ratio and retains the node buffer size. In HCCP, it is not necessary to maintain the global flow information and each node uses its current buffer size and network size to calculate its congestion level information. The congestion level is defined to indicate the current congestion level at each node. Each node individually assigns or reduces the data sending rate to avoid congestion. Congestion level is exchanged periodically between neighbor nodes. So, each node may use own and neighbor node's congestion level to prevent congestion.

4.1.7. CRRT

CRRT [34] (Congestion Aware and Rate-Controlled Reliable Transport in Wireless Sensor Networks) designed by Muhammad Mahbub and Choong Seon Hong in 2009. CRRT avoids congestion, controls sensors sending rate individually to success an optimal rate and provides fairness. CRRT succeed high transmission efficiency due to the reservation based MAC retransmission structure. CRRT supports multiple sinks and multiple consonant applications. Sink can assign rate to the individual sources collaboratively and maintain fairness for aggregate source rate.

4.1.8. CTCP

CTCP [35] (Reliable Transport Control Protocol for Sensor Networks) designed by Eugenia Giancoli, Filippe Jabour, Aloysio Pedroza in 2008. CTCP proposes packet delivery between a source node and sink. It detects and control congestion through the differentiation between transmission error losses and buffer overflow. When packet losses occurred, it uses two reliability levels and, in case of congestion, provides explicit signaling to break and resume data transmission. CTTP performs a significant increase in delivery reliability and decrease in packet loss. It is achieved by distributing responsibility of temporary message storage between two adjacent nodes. Moreover, distributed message storage demonstrates the protocol robustness during periods of disconnection, prior to an ACK confirmation. The base station takes the decisions that depend on the application requirements knowledge and control parameters with central characteristics.

4.2. End to end Congestion control Protocols

In this section, we will discuss about congestion control protocols that use end to end method. We will briefly express end to end protocols SRCP, STCP, ART, ESRT, TCCP, RCRT, TRCIIT and PORT.

4.2.1. SRCP

SRCP [36] (Sensor Reliability and Congestion Control Protocol) developed by Khan and Khan in 2010. It is reliability and congestion control protocol and also delay based end to end congestion control protocol for full rate adjustment. SCRP initiates the connection by sending a request [9]. Sink calculates RTT and adds this information to packet header. Then, it sends this packet as a reply. When the packet reaches to node, it starts to send the packets stored in his buffer. Packet timer value is changed at fixed intervals every 0.4 seconds. When data packets are received, sink node calculates the timestamp via current time (t) by subtracting the trip time. Sink saves received time values to time array. If there is any increase in the packet sending, the node sends the packet RTT values by adding the explicit congestion notification and node updates the RTT value.

If the packet sequence number is different than expected, it informs to sink for lost segments between two segments. If the sink node takes this packet, the sink terminates start phase and triggers controlled phase. In Fig. 3, SRCP packet header can be seen.

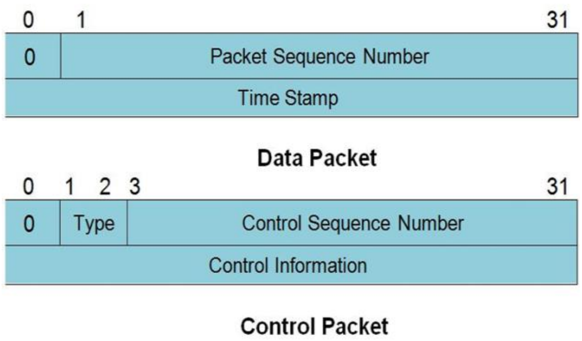


Fig3. SRCP Packet Header.

4.2.2. STCP

STCP [37] (Sensor Transmission Control Protocol) developed by Iyer, Venkatesan and Gandham in 2005. STCP is a generic end to end congestion control protocol for wireless sensor networks. STCP performs all functions at the sink node and each node may be source. It may adjust data flow type, transmission rate and reliability level. STCP provides controlled variable reliability, congestion detection and avoidance. It uses explicit congestion detection method. In this method, the nodes use two threshold values such as t_{lower} (low buffer status threshold) and t_{higher} (high buffer status threshold) to detect congestion. If a node's buffer status reaches to t_{lower} value, the congestion notification bit will be set. Congestion probability value can be determined by an approach as below. If the node's buffer status reaches to t_{higher} value, the node will set the congestion notification bit in all forwarded packets. When the sink receives these packets, it informs the congestion status to sensor nodes with ACK messages. When a node receives an ACK message, it sends the packets with a different route and adjusts packet sending rate.

4.2.3. ART Protocol

ART (An Asymmetric and Reliable Transport Mechanism) protocol has designed by Tezcan and Wang in 2007 [38]. It provides end to end upstream reliability, end to end query reliability and upstream end to end congestion control. It determines essential nodes (E-nodes) that they can cover all area. ART uses e-nodes for reliable data transfer to upstream and downstream nodes and loss recovery. It has four stages. The first stage, non-essential nodes do not participate end to end communication. In second stage, congestion control methods regulate data traffic. In third stage, a few nodes are involved in loss recovery schemes. In fourth stage, ART takes care of energy efficiency using congestion control. ART uses both ACK and NACK messages. It is assumed that congestion occurs if a timeout happens without receiving any ACK from the sink. In this case, e-node informs neighbor nodes that are not e-nodes to reduce data sending rate until the congestion problem is solved. As a result congestion problem is solved only by using e-nodes and congestion notification information is propagated upon them [32].

4.2.4. ESRT

ESRT (ESRT: Event-to-Sink Reliable Transport in Wireless Sensor Networks) designed by Akan and Akyildiz [24] in 2004. It provides end to end upstream congestion control and upstream reliability. Firstly, in ESRT protocol, the sink needs to regularly calculate the reliability (r) value according to successfully received packets in a fixed time interval. Then, sink computes the required sensor report frequency from (r) and finally, it reports f value to sensor nodes with high power. The nodes that get f value calculate reporting interval and control the buffer status to guess congestion. If a node detects congestion, the congestion enable bit in event report packet is set. When report packet arrives to the sink node, it gets information about network's congestion level. ESRT conserves energy by changing f reporting value.

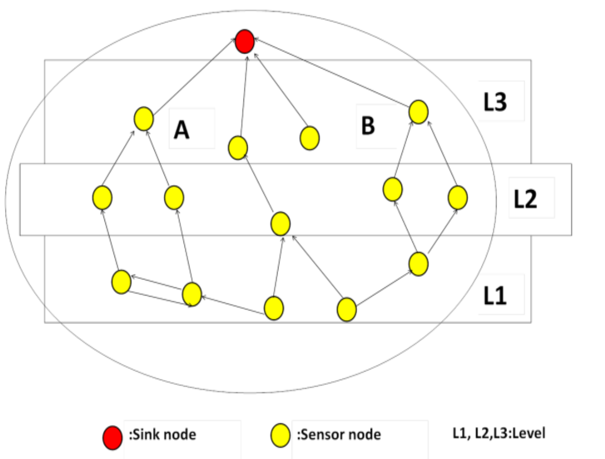


Fig.4 Tournament protocol network model.

4.2.5. TCCP

TCCP (Tournament based Congestion Control Protocol) [39] designed by Lee, Jeong and Jin in 2011. TCCP uses end to end congestion control method to decrease congestion. In Fig. 4, Tournament network model can be seen. The proposed tournament method provides a different priority queue for each level of packet streams. Thus, the priority queue plays the key role to reduce the congestion and determine the importance of a stream. TCCP has three methods to reduce congestion such as tournament decision, best-fit control strategy and service differentiation [39]. Firstly, the tournament decision [28] selects the packets with less overhead and larger link by comparing two or more packets [39]. Secondly, in best-fit control strategy is the process to decide the largest relevance of packet streams. If not establishing the best-fit control strategy, streams suffer from the cost effectiveness and stream overhead [39]. Thirdly, the TCCP determines importance level or priority by the best-fit control algorithm. If the bandwidth usage rate is given for a service and the stream is activated, then the bitrate range is assigned and the service is differentiated according to the bandwidth usage rate [40]. Consequently TCCP protocol decreases congestion, reduces packet loss, provide energy efficiency, and so improves quality of service.

4.2.6. RCRT

RCRT (Rate-Controlled Reliable Transport Protocol for Wireless Sensor Networks) [41] designed by Jeongyeup Paek and Ramesh Govindan in 2007. RCRT protocol is suitable for constrained sensor nodes. RCRT uses end to end explicit loss recovery, but places all the congestion detection and rate adaptation functionality. It places its congestion control functionality at the sink, whose perspective into the network enables better aggregate control of traffic. It supports multiple concurrent applications, and is robust to network dynamics. Sinks make rate allocation decisions; they are able to achieve greater efficiency since they have a more comprehensive view of network behavior. It has two important advantages as efficiency and flexibility.

4.2.7. TRCCIT

TRCCIT (Tunable Reliability with Congestion Control for Information Transport in Wireless Sensor Networks) [42] designed by Faisal Karim Shaikh, Abdelmajid Khelil, Azad Ali and Neeraj Suri in 2010. TRCCIT protocol is a tunable reliability with congestion control for information transport in WSNs. TRCCIT provides desired application reliability despite developing network conditions by adaptive retransmissions and conquering the unnecessary information. Reliability of information transport is achieved by HACK mechanism helped by localized retransmission timer management. TRCCIT efficiently monitors the packet information flow and adapts between single path and multiple paths in order to improve congestion such that desired application reliability is maintained.

4.2.8. PORT

PORT (A Price-Oriented Reliable Transport Protocol for Wireless Sensor Networks [43] designed by Yangfan Zhou and Michael R. Lyu in 2005. PORT protocol facilitates the sink to achieve reliability. Under the constraint that the sink must obtain enough fidelity for reliability purpose, PORT protocol minimizes energy consumption with two schemes. One is based on the sink's application-based optimization approach that feeds back the optimal reporting rates. The other is a locally optimal routing scheme according to the feedback of downstream communication conditions. PORT can adapt well to the communication conditions for energy saving while maintaining the required reliability level.

4.3. Hop by hop and end to end Congestion control Protocols

In this section, we will discuss about congestion control protocols that support both hop by hop and end to end congestion control methods. We will briefly express CODA and Siphon protocols that use these methods.

4.3.1. CODA Protocol

CODA (Congestion Detection and Avoidance) designed by Wan, Eisenman and Campbell [20] in 2003. CODA is an upstream congestion control protocol that supports hop by hop and end to end method. CODA protocol detects congestion by the buffer status and the channel load rate. CODA sends congestion information with a message to the upstream nodes. After upstream nodes receive this message, they decrease their transmission rates. In other words, if a message doesn't arrive to upstream neighbors within a certain time, nodes increase linearly sending rate. CODA uses closed loop end to end method using AIMD (Additive increase / multiplicative decrease). It regulates node sending rate by end to end approach. Before a sensor node sends data, it controls the channel load periodically and if wireless channel is busy, congestion control bit in the header of packet is set. Congestion control bit is used to inform sink. When the sink receives a packet that has congestion notification bit, it sends ACK message to the source node. When source node takes this message, it decreases packet sending rate. When the congestion problem is solved, the sink node sends an ACK control message to the source node. So it increases data sending rate.

4.3.2. Siphon Protocol

Siphon protocol designed by Wan, Eisenman, Campbell and Crowcroft [44] in 2005. Siphon protocol has multi-radio virtual sinks (VS) that manage the traffic load on upstream flow. Virtual sinks are supported by minimum two different radios. One of them is poor radio and other is powerful. The poor radio interface connects sensor nodes to each other. Second radio connects the virtual sinks to each other.

In addition to congestion detection method used in CODA, Siphon uses post-facto scheme. Sink monitors measured application fidelity and event data quality. If measured application fidelity drops under threshold value, it starts virtual sink signaling. Siphon redirects traffic from sensor nodes to virtual sinks. As a result, congestion decreases quickly. Siphon uses hop by hop and end to end congestion control together. If there is no congestion, the hop by hop method is used. If congestion occurs, it is used the hop by hop method between source nodes and end to end method between the Virtual Sink and the sink.

4.4. Comparison of the Congestion Control Protocols

In this section, we compare the congestion control protocols in terms of some criterias such as energy efficiency, fairness, reliability, congestion detection and congestion avoidance method. In Table 3, it is shown the comparison results. The table indicates that congestion protocols detect the congestion with using different parameters such as packet service time, queue length, channel load etc. Even though, PCCP, PHTCCP, SenTCP, CCF, SRCP, ART, TCCP, RCRT and PORT protocols only use packet service time value, HCCP, STCP, TRCCIT protocols use Packet Service Time and Queue Length to detect congestion with together and despite CTCP, CRRT and ESRT protocols use Queue Occupancy, Fusion use Queue Length, CODA and Siphon use Channel Load and Queue Length to detect congestion with together.

Some protocols use hop-by-hop congestion control method, besides the others use end-to-end congestion detection method. Only, CODA and Siphon use these two methods together. According to energy efficiency criteria, most of the proposed protocols are successful except HCCP and Fusion. PCCP, PHTCCP, SenTCP, CCF, Fusion, HCCP, TCCP, CODA and Siphon protocols only have congestion control, but CRRT, SRCP, STCP, ART, ESRT, RCRT, TRCCIT and PORT protocols have congestion control and reliability mechanism.

When some protocols are analyzed in terms of fairness, PCCP, Fusion, CRRT, TCCP, RCRT and PORT protocols have strong fairness, PHTCCP, SenTCP, HCCP, SRCP, STCP, ART, ESRT, CODA and Siphon protocols have weak fairness. Each protocol is used in different applications and has been tested using different parameters. In Table 1, it is shown protocol testing applications. Congestion control protocols are tested in different simulation environments. PHTCCP, HCCP, CRRT, SRCP, ART, ESRT, TCCP, PORT and CODA protocols were tested by using NS-2 simulator; SenTCP, CCF, Fusion, RCRT and Siphon protocols were tested by using Tiny-OS real testbed and CTCP, STCP and TRCCIT protocols were tested by using TOSSIM simulator. SenTCP, CCF, Fusion, RCRT and Siphon have a real implementation besides the others have a simulation models. In Table 2, it is shown the simulation environments.

Table1. Protocol Testing Applications.

Protocols	Applications
PCCP	Heterogeneous concurrent multiple applications
PHTCCP	Heterogeneous concurrent multiple applications
SenTCP	-
CCF	Fairness in applications: large area temperature monitoring
Fusion	High-volume bursty traffic applications and fairness
HCCP	General sensing application
CRRT	High-rate applications: imaging, acoustic localization
CTCP	Heterogeneous concurrent multiple applications
SRCP	Heterogeneous concurrent multiple applications
STCP	Heterogeneous concurrent multiple applications
ART	Mission critical applications like country border security
ESRT	Event detection applications: signal estimation / tracking
TCCP	General sensing application
RCRT	High-rate applications: imaging, acoustic localization
TRCCIT	Heterogeneous concurrent multiple applications
PORT	General sensing application
CODA	General sensing application
Siphon	Generic data dissemination application

Table2. Protocol Simulation Environments

SIMULATION ENVIRONMENTS		
NS-2	**TINY-OS**	**TOSSIM**
PHTCCP	SenTCP	CTCP
HCCP	CCF	STCP
CRRT	Fusion	TRCCIT
SRCP	RCRT	
ART	Siphon	
ESRT		
TCCP		
PORT		
CODA		

Table3. Comparison of congestion control Protocols

Protocols	Energy Efficiency	Reliability	End to End	Hop By Hop	Congestion Detection Method	Fairness
PCCP	Strong	No	No	Yes	Packet Service Time	Strong
PHTCCP	Strong	No	No	Yes	Packet Service Time	Weak
SenTCP	Strong	No	No	Yes	Packet Service Time	Weak
CCF	Strong	No	No	Yes	Packet Service Time	Strong
Fusion	Medium	No	No	Yes	Queue Length	Strong
HCCP	Weak	No	No	Yes	Packet Service Time / Queue Length	Weak
CRRT	Strong	Yes	No	Yes	Queue Occupancy	Strong
CTCP	Strong	Yes	No	Yes	Queue Occupancy	Medium
SRCP	Strong	Yes	Yes	No	Packet Service Time	Weak
STCP	Strong	Yes	Yes	No	Packet Timeout value/ Queue Length	Weak
ART	Strong	Yes	Yes	No	Packet Service Time	Weak
ESRT	Strong	Yes	Yes	No	Queue Occupancy	Weak
TCCP	Strong	No	Yes	No	Packet Service Time	Strong
RCRT	Strong	Yes	Yes	No	Packet Service Time	Strong
TRCCIT	Strong	Yes	Yes	No	Packet Service Time / Queue Length	Medium
PORT	Strong	Yes	Yes	No	Packet Service Time	Strong
CODA	Strong	No	Yes	Yes	Queue Length / Channel status	Weak
Siphon	Strong	No	Yes	Yes	Channel Load/ Queue Length	Weak

5. Conclusions

Energy efficiency is a big challenge in WSNs, since sensor nodes have a little battery capacity. Congestion control protocols prevent unnecessary packet transmissions; improve energy efficiency and network throughput. Therefore, they become so popular research area in recent years. In this article, we examine representative congestion protocols proposed in recent years according to energy efficiency, fairness, congestion detection method, congestion avoidance method and reliability. According to the comparison results, energy efficient, reliable and fair congestion control protocols are needed to be developed better. According to the results, if congestion control protocols have reliability mechanisms, network throughput and energy efficiency will be better. So in future, transport control protocols must provide reliability and congestion control mechanism.

References

1. E. Kalipci, C. Ozdemir, S. Sahinkaya Evaluation of manageable biological waste utilization of Konya in terms of environment and energy recovery , Energy Education Science And Technology Part A, 7(1), 35–42 ,(2011)
2. Patel Femina and Patel Sanjay, Carbon monoxide oxidation on LaCoO3 perovskite type catalysts prepared by reactive grinding, Res. J. Recent Sci., 1(ISC-2011), 152-159 (2012)
3. Mane T.T. and Raskar Smita S., Management of Agriculture Waste from Market Yard Through Vermicomposting, Res. J. Recent Sci., 1(ISC-2011), 289-296 (2012)
4. Mane T.T. and Hingane Hemalata N, Existing situation of Solid waste management in pune city, India, Res. J. Recent Sci., 1(ISC-2011), 348-351 (2012)
5. Pathak C., Mandalia H.C. and Rupala Y.M., Biofuels: Indian Energy Scenario, Res.J.Recent Sci., 1(4), 88-90 (2012)
6. B. Yelmen, T. Ustuner, M. Ustuner, Determining the potential of solar energy and benefiting from this potential using photovoltaic system in Turkey , Energy Education Science And Technology Part A, 27(2), 347-358, (2011)
7. T. G. Ozbalta, N. Ozbalta, Theoretical and experimental analysis of the solar energy gain of transparent insulated external wall in climatic conditions of Izmir, Energy Education Science And Technology Part A, (25), 69-86, (2010)
8. T. V. Ramachandra, Solar energy potential assessment using GIS, Energy Education Science And Technology, (18), 101-114, (2007)
9. Genwa K.R. and Chouhan Anju, Optimum efficiency of photogalvanic cell for solar energy conversion and storage containing Brilliant Black PN-Ammonium lauryl Sulphate – EDTA system, Res. J. Recent Sci., 1 (ISC-2011), 117-121 (2012)
10. Imal, M. Sekkeli, C. Yildiz, O. F. Kececioglu, Wind energy potential estimation and evaluation of electricity generation in Kahramanmaras, Energy Education Science And Technology, Turkey, 30(1),661-672, (2012)
11. Dev Nikhil, Attri Rajesh, Mittal Vijay, Kumar Sandeep, Mohit, Satyapal and Kumar Pardeep, Economic and Performance Analysis of Thermal System Res.J.Recent Sci., 1(4), 57-59 (2012)
12. A. C. Cakmak, Energy saving and a research about consumers' perceptions from the energy saving products: An application at Kahramanmaras city centre, Energy Education Science And Technology Part B, 4(1), 259-270, (2012)
13. Rao, Y. Zhang, S. Wang, Energy saving of power battery by liquid single-phase convective heat transfer, Energy Education Science And Technology, 30(1), 103-112, (2012)
14. Akyıldız I.F., Su. W. Sankarasubramaniam Y., Cayırcı E., Wireless Sensor Networks: A Survey, Computer Networks, 38, 393-422, (2002)
15. Zhang Chun; Fei Shumin; Zhou Xingpeng , Energy Efficient Data Collection in Hierarchical Wireless Sensor Networks, CHINA COMMUNICATIONS, 9(9), 79-88, (2012)
16. Cui Qimei; Deng Jingang; Zhang Xuefei , Compressive Sensing Based Wireless Localization in Indoor Scenarios, CHINA COMMUNICATIONS, 9(4), 1-12, (2012)
17. A. Alaybeyoglu, K. Erciyes, A. Kantarci, O. Dagdeviren, Tracking Fast Moving Targets in Wireless Sensor Networks, IETE Technical Review, 27(1), 46-53, (2010)
18. Nie Zedong; Guan Feng; Huang Jin, Low Power Single-Chip RF Transceiver for Human Body Communication., CHINA COMMUNICATIONS, 9(9), 1-10, (2012)
19. Wang, C., Li, B.Sohraby, K. Transport Protocols and Quality of Service, in Wireless Sensor Networks: A Networking Perspective , A John Wiley & Sons INC. Publication, 343-366, (2009)
20. C. Y. Wan, S. B. Eisenman and A.T. Campbell, CODA: Congestion detection and avoidance in sensor networks, in Proceedings of ACM Conference on Embedded Networked Sensor Systems, Los Angeles, CA, 266-279 , (2003)
21. B. Hull, K. Jamieson, H. Balakrishnan, Mitigating congestion in wireless sensor networks, in Proceedings of ACM Conference on Embedded Networked Sensor Systems,134-147., (2004)
22. C.-T. Ee, R. Bajcsy, Congestion control and fairness for many to one routing in sensor networks, in Proceedings of ACM Conference on Embedded Networked Sensor Systems, 148-161. , (2004)
23. C. Wang, B. Li, K. Sohraby, M. Daneshmand, Y. Hu, Upstream congestion control in wireless sensor networks through cross - layer optimization, IEEE Journal on Selected Areas in Communications, 25(5), 786-795, (2007)
24. Y. Sankarasubramaniam, O. B. Akan, I. F. Akyildiz, ESRT:Event - to - sink reliable transport in wireless sensor networks, in Proceedings of ACM International Symposium on Mobile Ad Hoc Networking and Computing, 177-188., (2003)
25. C. Wang, K. Sohraby, B. Li, W. Tang, Issues of transport control protocols for wireless sensor networks, Proceedings of International Conference on Communications, Circuits and Systems, 422-426, (2005)
26. K.Sohraby, D. Minoli, T. Znati, Wireless Sensor Networks Technology, Protocols and Applications, Published by John Wiley & Sons, Inc., Hoboken, New Jersey, 361, (2007)
27. H. Karl, A. Willig, Transport Layer and Quality of Service in Protocols and Architectures for Wireless Sensor Networks, John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, 361, (2005)
28. C. Wang, M. Daneshmand, B. Li, K. Sohraby, A survey of transport protocols for wireless sensor networks, IEEE Network Magazine, 34-40, (2006)

29. C. Wang, K. Sohraby, V. Lawrence, B. Li, Y. Hu, Priority-based congestion control in wireless sensor networks, Proceedings of the IEEE International Conference on Sensor Networks, Ubiquitous, and Trustworthy Computing, (2006)
30. M.M. Monowar, M.O. Rahman, A.K. Pathan, C.S. Hong, Congestion control protocol for wireless sensor networks handling prioritized heterogeneous traffic, Proceedings of the 5th Annual International Conference on Mobile and Ubiquitous Systems Computing Networking and Services, (2008)
31. Wang C., Sohraby K., Li B., SenTCP: A hop-by-hop congestion control protocol for wireless sensor networks, Proc. IEEE INFOCOM, Miami, (2005)
32. Md. A. Rahman, A. E. Saddik, W., Gueaieb Wireless Sensor Network Transport Layer: State of the Art, Sensors Lecture Notes Electrical Engineering, 21, 221-245, (2008)
33. J.P. Sheu, L.J. Chang, W., K. Hu, Hybrid Congestion Control Protocol in Wireless Sensor Networks, In Proceedings of Journal of Information Science and Engineering, 1103-1119, (2009)
34. Alam M, Hong CS. CRRT: congestion-aware and rate-controlled reliable transport in wireless sensor networks. IEICE Transactions on Communications, E92(B), 184–9, (2009)
35. Giancoli E, Jabour F, Pedroza A. CTCP: Reliable Transport Control Protocol for sensor networks. In: International conference on intelligent sensors, sensor networks and information processing, 493–8, (2008)
36. R. Khan, F.A. Khan, SRCP: Sensor Reliability and Congestion Control Protocol, CIT '10 Proceedings of the 10th IEEE International Basaran C, Kang K-D, Suzer MH, Chung K, Lee H-R, Park K-R., Bandwidth consumption control and service differentiation for video streaming, Computer Communications and Networks, 1, 1–7, (2008)
37. Paek J, Govindan R. RCRT: rate-controlled reliable transport for wireless sensor networks. In: Proceedings of the 5th international conference on embedded networked sensor systems,305–19, (2007)
38. Shaikh FK, Khelil A, Ali A, Suri N. TRCCIT: tunable reliability with congestion control for information transport in wireless sensor networks. In: Proceedings of the international wireless internet conference (WICON), Singapore, (2010)
39. Zhou Y, Lyu MR. PORT: a price-oriented reliable transport protocol for wireless sensor network. In: Proceedings of 16th IEEE international symposium on software reliability engineering. 117–126, (2005)
40. C. Y. Wan, S. B. Eisenman, A. T. Campbell, J. Crowcroft, Siphon: Overload traffic management using multi - radio virtual sinks in sensor networks, in Proceedings of ACM Conference on Embedded Networked Sensor Systems, 116-129, (2005)
41. Conference on Computer and Information Technology, 1542-1548, (2010)
42. Y. G. Iyer, S. Gandham, S. Venkatesan, STCP: A generic transport layer protocol for wireless sensor networks, in Proceedings of 2005 14th IEEE International Conference on Computer Communications and Networks, 449-454, (2005)
43. Tezcan N.,Wang W. ART, an asymmetric and reliable transport mechanism for wireless sensor networks, International Journal of Sensor Networks, 1-14, (2007)
44. C. Lee, T.W. Jeong, S. Lian, Tournament-based congestion control protocol for multimedia streaming in ubiquitous sensor networks, International Journal of Communication Systems archive, 24, 1246-1260, (2011)