A Survey of Transport Layer Protocols for Wireless Sensor Networks

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ABSTRACT
The reliability of data transfer is vital for commercial and enterprise applications of Wireless Sensor Networks (WSN). Likewise, mission-oriented and critical military applications of these networks demand dependable and timely data transport. This reliability is required for in-bound data, from Internet node to sensor nodes which comprises of code updates, as well as for out-bound data from sensor nodes to base station or gateway which comprises of important data reported by sensor nodes. Although TCP is a time-tested transport layer protocol of Internet that ensures reliability, flow control and congestion control, being a heavy protocol, it is considered unsuitable for resource constrained sensor networks. As a result new transport layer protocols have been developed for these networks. Nonetheless efforts are directed towards making TCP suitable for sensor networks. This paper presents a survey of transport layer protocols and approaches to achieve reliable data communication in general wired-cum-wireless networks and particularly in WSN.

General Terms
Survey, Wireless Networks, Protocols.

Keywords
Wireless Sensor Networks, Reliability, Transport Layer, TCP.

1. INTRODUCTION
Wireless Sensor Networks (WSNs) are a type of Low-Rate Wireless Personal Area Networks (LR-WPANs) standardized as IEEE802.15.4 [1]. The WSN is an ad-hoc network that comprises of end devices (sensor nodes) that communicate through wireless medium. These nodes are fitted with sensors, radio transceivers, microcontrollers and battery sources. Sensor nodes are available in different sizes and have varying costs and resources depending upon application requirements, business demands, sensor network size and complexity of application. Applications of WSN are diverse including home automation and traffic control to more complex and critical applications like battlefield monitoring, shooter localization, industrial process control, patient observation, habitat supervision, and environmental monitoring etc. Most of these applications are deemed useful when these networks collaborate with wired networks and/or other wireless networks. In this research work these collaborations or interconnections are studied, problems and bottlenecks are identified and solutions are presented.

It is known that TCP performs inadequately in varied environments connecting wired and wireless networks [2]-[4]. In such heterogeneous networks, splitting TCP connection into two parts, wired and wireless, increases throughput and fairness. In [5], comparison of TCP performance improving mechanisms over wireless links is presented. I-TCP, Split TCP and Semi-split TCP [5]-[8] suggest some variants of this technique and demonstrate that splitting TCP across proxy achieves TCP performance gain. Nevertheless, performance gain is restricted by congestion at proxy and asymmetry between links. Under these conditions, the proxy can turn out to be the bottleneck of connection. When a large number of connections are supported across proxy, buffer overflow can occur at proxy. Research is underway for making TCP feasible for resource constrained multi-hop WSNs. Dunkels et al. in [9] have proposed distributed TCP caching that suggests local TCP segment retransmissions in WSN in case of packet loss. The idea of multipath TCP is presented and enhanced in [10]. In [7] Yusung et al. propose an Adjustable Parallel TCP (AP-TCP) which is a new scheme to control the aggregate throughput of parallel TCP flows. The AP-TCP can adjust the aggregate throughput to a desired level irrespective of the number of parallel TCP flows. To adjust the aggregate throughput, they modify the increment factor of each parallel TCP flow to K^2/N^2 where N is the number of parallel TCP flows and K is a value equivalent to any desired level for the aggregate throughput. Once K is given, the AP-TCP attempts to have K times more bandwidth than a single TCP flow when they are competing on the same network path. Kuschnig et al. in [11] claim that TCP-based video streaming encounters difficulties in unreliable networks with unanticipated packet loss and propose a client-driven video transmission scheme which utilizes multiple HTTP/TCP streams.

In this paper, we explore transport layer protocols for general wired-cum-wireless networks we identify issues of TCP implementation in these networks, and then present a detailed survey of transport layer protocols in wireless sensor networks. This paper helps the reader to understand the importance and challenges for reliable data communication in these networks. The reader is familiarized with all the different approaches suggested by researchers in recent years towards solving the problem of efficient transport layer protocol in WSNs. In Section 2, we discuss TCP performance in wireless and wired-cum-wireless networks, specifically in WSNs. Section 3 present approaches for transport layer solutions for WSNs. These approaches are classified as TCP improvement approaches, parallel TCP approaches and novel transport layer protocols specifically designed for WSNs. Section 4 concludes the paper.

2. TCP PERFORMANCE IN WIRELESS NETWORKS

2.1 General Wired-cum-Wireless Networks

TCP is time-tested transport layer protocol in Internet that implements end-to-end reliability, flow control and congestion control. This protocol was developed for wired links but lately Internet is being extended to include wireless links as well. For such wired-cum-wireless networks, TCP has been found to lack suitability as well as efficiency. In [2] it is stated that some of the main factors that result in inferior TCP performance in these networks are:

2.1.1 Low Bandwidth

Wireless networks have limited bandwidths as compared to wired networks. In Wireless Local Area Networks (WLANs) bit rates are around 10-100 Mbps, Wireless Personal Area Networks (WPANs) bit rates are around 2-10 Mbps. In heterogeneous networks comprising wired-cum-wireless links, mismatched bandwidths of the two networks results in bottleneck that affects TCP. Thus limited bandwidth in wireless networks is responsible for degradation in TCP performance.

2.1.2 High Latency

As compared to wired links, latency of data transfer is more in wireless links. TCP congestion window at the sender end evolves in proportion to acknowledgements received from receiver. As a result of long delays in wireless links, congestion window evolves slowly which affects throughput.

2.1.3 Arbitrary Losses

The transmission losses on wireless links are considerably more as compared to wired links. The losses cause packets to drop thus resulting in sender not receiving acknowledgments inside the retransmit timeout. The sender retransmits packet, exponentially reduces timer and cuts the congestion window to unit. Thus when it occurs repeatedly, it results in reduced throughput. In wired-cum-wireless, wireless link is generally the last link and losses on this last link result in end-to-end retransmission by TCP and thus reduces throughput.

2.1.4 Wireless Network Mobility

When wireless networks support mobility like cellular networks where end users are mobile, handoff takes place when user moves from one cell to another such that new channel is allocated through other cell's base station and all control information has to be shifted. There could be very short loss of connectivity resulting in losses which can cause reduction in TCP congestion window this causing reduced throughput. Similarly in ad hoc networks, topology changes can cause losses resulting in affecting throughput.

2.1.5 Underutilization of Capacity

Services like web browsing and e-mail involve small amount of data transfer between the client and the server. The TCP sender increases its congestion window progressively as it receives acknowledgments from the receiver (Slow Start). There is a high probability that the transfer completes even before the sender's window reaches the maximum possible size. This results in under utilization of the network capacity.

2.1.6 Power Utilization

Retransmissions as a result of packet losses can cause long connection duration and thus more power is consumed. Power utilization is an important issue in case of battery operated end devices like laptops, PDAs, wireless phones and wireless sensor nodes.

As stated earlier, TCP was basically developed for wired Internet. In order to make it suitable for wireless networks in terms of performance parameters like throughput and latency, it has to be adjusted. Researchers have proposed different ways to reduce the effect of non-congestion-related losses on TCP performance over networks that have high-loss wireless links. Some researchers have tried to propose link layer solutions thus shifting the solution at the lower layer in order to hide link problems from upper layer. Some others have suggested changes at the transport layer i.e. changes in TCP in order to adjust its performance according to wireless medium. While there are many researchers who have proposed to abandon TCP and have attempted to develop new transport protocols specifically developed for wireless networks. In this regard new transport layer protocols are suggested for different types of wireless networks according to their particular features. Protocols developed for cellular networks are specifically developed for conditions and issues in these networks, protocols developed for sensor networks are developed according to their features and so on.

2.2 Wireless Sensor Networks

If we specifically focus on ad hoc networks, deterioration in TCP performance in these networks is a result of following differences [2]:

2.2.1 Impact of Re-estimation of Route

Due to mobility of nodes in ad hoc networks, routes can break and as a result new routes have to be computed. The route discovery of new routes can take longer time than the timeout interval at the sender. This causes timeout at sender and can invoke congestion control. Thus after the new route discovery throughput would be reduced as TCP is in slow start stage. In networks with high mobility, due to frequent breaking of previous routes and making of new routes, overall throughput would be reduced.

2.2.2 Impact of Network Division

Network division or partitioning is a major issue in ad hoc networks. The send and the receiver can be in separate partitions. In such a case packets are not delivered to the receiver. The sender times out and retransmits packets. This way, packets are retransmitted again and again but do not reach the receiver as receiver is in another partition. For every retransmission, the sender doubles the timeout interval until it reaches the maximum value. Even when the sender and receiver get connected, the lost packets are not transmitted by sender before considerable delay.

2.2.3 Congestion Window

TCP congestion window is defined as the adequate data rate for a specific route. As discussed above, in ad hoc networks, the routes often change thus the connection between the sender congestion window and actual acceptable data rate for route will not hold. The congestion window for a route can be too large for a newer route and the sender may transmit at a high rate resulting in network congestion.

In [3] the authors present current and future challenges in the design of transport layers for sensor networks. Reliable data communication in wireless sensor networks is complex due to the following features of these networks:

- Reduced processing abilities and less communication range of sensor nodes.
- Close location to ground results in signal reduction or fading which results in asymmetric links.
- Close location to ground and changing topography leads to shadowing which can practically isolate sensor nodes from the rest of the network.
- The conservation of nodes energy requires unused nodes and wake only when needed.
- Sensor nodes are deployed densely which can create channel contention and congestion.

Conventional transport layer protocols, like TCP, are not appropriate for seriously resource constrained WSNs which have features that are quite different from conventional wired networks like the Internet.

In [3] the authors advocate for the need of a standard transport layer protocol in WSNs and outline challenges in designing a transport layer protocol that is suitable according to the constraints of WSNs. This paper does not propose a new transport layer protocol for WSNs but highlight the problems and challenges in the design of transport layer protocols for these networks. The authors also compare some of the notable transport layer protocols developed for WSNs.

3. APPROACHES TO IMPROVE TCP PERFORMANCE

3.1 General Wireless Networks

In [4] Balakrishnan et al. report that unlike wired networks, congestion is not the only source of packet loss in wireless networks. Networks with wireless and lossy links also experience considerable losses as a result of bit errors and handoffs. They perform an in-depth evaluation of the suitability of various methods that are directed towards improving TCP performance over wireless links in LAN and WAN settings. The authors observe that there are two different methodologies to improving TCP performance in wireless networks:

- Conceal non-congestion-related losses from TCP sender, so that no modifications are needed in the existing TCP implementations. In this approach, transport layer remains oblivious to the losses due to link features.

- Create link related loss awareness in senders, so that senders do not run congestion control algorithms when losses are owing to link features and not congestion related. But discriminating various kinds of losses is a difficult hard problem.

- Hybrid of the two approaches, both of the above stated features can be combined to propose wireless-aware transport layer along with link layer schemes. This paper classifies approaches into three categories:

3.1.1 End-to-end approaches

These protocols try to deal with losses with the use of Selective ACKs (SACKs) and Explicit Loss Notification (ELNs). Two types of SACK-related proposals are taken into account: standard SACK, which propose ACK for three recent non-contagious blocks, and SMART, which propose cumulative ACK and the sequence number of the packet that caused the SACK.

3.1.2 Split-connection approaches

In this category, end-to-end connection is divided into two, one wireless and the other wired. Split connection approaches experience many problems. Wireless link forms the bottleneck of the connection for wired link. It results in double processing at the gateway. The conventional end-to-end TCP semantics is violated. There is a large quantity of states in the intermediate point.

3.1.3 Link-layer approaches

The link layer approaches conceal link-related losses from the transport layer by employing link level retransmissions and forward error correction (FEC) in order to evade timer mismatch between link layer and transport layer and to avoid duplicate acknowledgments triggering retransmissions.

The authors conclude that the split-connection-based proposals are not comparable to TCP-aware link layer protocols. SACK-based TCP approaches are effective in lossy wireless links. End-to-end TCP approaches have the merit of not requiring changes at the intermediate nodes.

In [5] and [6], Bakre and Badrinath explain the design and execution of I-TCP; an indirect transport layer protocol for mobile hosts. I-TCP employs Mobility Support Routers (MSRs) to offer transport layer transfer between mobile hosts and fixed network hosts. With I-TCP, the problems related to mobility and unreliability of wireless link is handled within wireless link and no changes are incorporated on wired hosts. In I-TCP there are separate TCP ACKs in wired and wireless parts of connection thus end-to-end TCP ACKs are not implemented.

I-TCP has following features:

- TCP flow control and congestion control are separately implemented on wired and wireless parts of connection. This is suitable due to different features of wired and wireless links where wired links are high bandwidth with minimal losses and wireless links are bandwidth starved with more losses.

- A distinct transport protocol for wireless part can implement notification of disconnections and available bandwidth to upper layers which can be utilized by link aware and location aware applications.

- Due to separate base station to manage wireless network affairs, the wireless hosts can run simple protocols for wireless side of communication.

I-TCP is matched with TCP/IP on wired network and is based on following model:

- A single transport layer connection between the mobile host and fixed host is formed as two separate transport layer connections, one over wireless links between the mobile host and the router and other over wired links between router and fixed host.

- If mobile host changes cell during the I-TCP connection, the center point of connection switches to new router.

- The fixed host is ignorant of the indirection and is not concerned when mobile host changes cells i.e. when the center point of connection moves from one router to the other.

For any TCP connection, specific nodes along the connection adopt the role of proxies for that connection. These proxy nodes store packets in buffer manage rate control. This buffering of packets by intermediate nodes facilitates lost packets to be restored from the nearest proxy to the receiver. The rate control assists in managing congestion on inter-proxy packets. They implement shorter TCP connections by introducing the concept of proxy nodes and achieve parallelism in the network. They show through simulations that the use of proxies improves overall throughput and minimizes unfairness. They claim that using TCP proxies is useful for enhancing TCP performance in ad hoc networks.

In [11] Kuschnig et al. report that video streaming based on TCP faces problems due to packet loss. Due to high round trip times in unreliable networks, the effectual throughput degrades swiftly and results in TCP connection resets or stalls. In their work they suggest a client-driven video transmission scheme which uses a number of TCP streams. The scheme is highly resilient to unexpected packet loss and thus minimizes variations in throughput. The scheme is easily deployable in existing network framework. It also adapts to congestion in network because it is built on top of TCP and is not prone to network errors and bandwidth fluctuations contrary to a single TCP connection. They use multiple http streams each over a separate TCP thus their suggested approach is effectively parallel TCP streams managed at the application layer for http data transfer. In this approach, no changes are suggested at the transport layer and effectively changes are implemented at the application layer. Thus this approach can be categorized as an application layer parallel TCP management.

Semi split TCP in [13] retains end-to-end semantics of TCP for split TCP. Xie et al. suggest that it has been proved that breaking the TCP connection across wired and wireless networks through proxy results in performance improvement. But at the down side it results in violating the end-to-end TCP semantics which can create problems for applications that demand or rely on end-to-end guarantee of TCP. They introduce an innovative technique called Semi-Split TCP to solve this issue without compromising the advantages of Split TCP.

The authors claim that a number of presented split TCP protocols improve TCP performance but compromises TCP end-to-end semantics. This violation of end-to-end TCP semantics may pose problems in applications that involve transaction-based data transfer. Their proposed protocol is suitable for most of the existing TCP implementations. They show that by intelligent manipulation of proxy buffer and ACKs received from wireless network, the TCP proxy has the ability to drastically enhance network throughput while maintaining the end-to-end TCP semantics. In semi-split-TCP architecture, there are two agents that are responsible to interact with the sender and the mobile host respectively. These agents are named semi-split receiver and semi-split sender. The agents “hook” the TCP packets from network layer. The semi-split receiver agent buffers TCP data and acknowledges the sender using spoofed ACK. The semi-split sender agent forwards the buffered data to the mobile host by using enhanced transport layer protocol.

3.2 Wireless Sensor Networks

The transport layer protocols in WSN are required to be energy-efficient in addition to typical transport layer requisites of reliability, congestion control and flow control [3]. The need for a transport layer protocol in WSNs has been contemplated. Researchers suggest implementing reliability in terms of loss discovery and revival in lower layers like data link layer and ignoring congestion control as they think it is not an issue because sensor nodes spend most of the time sleeping resulting in sparse traffic in the network. TCP/IP has been used effectively in wired Internet and other wireless networks. Many researchers support TCP as a suitable transport layer protocol for WSN due to its being a time-tested Internet protocol. However at the down side, heavy protocol stack, unnecessary header overhead and end-to-end reliability makes it unsuitable for use in WSNs. But TCP can be made suitable for WSN through modifications. TCP/IP may not be suitable for standard sensor nodes in a WSN, but may still be used at the sink to communicate with other remote endpoints.

Transport layer protocols in WSN can generally be categorized into TCP improvement approaches including parallel TCP approaches and new transport protocols. We discuss TCP improvement approaches first and then present some promising customized protocols specially developed for WSN.

3.2.1 TCP Improvement Approaches

In [14] the authors report that transport connections set up in wireless ad hoc networks face issues like high bit error rates, frequent route changes, and partitions. If TCP is implemented over such connections without modification, the throughput of the connection is monitored to be considerably less because TCP considers lost or delayed acknowledgments as congestion. They propose a scheme which introduces a new layer called ATCP between network and transport layers and plays its role in solving above stated problems in order to support high throughput. This is achieved by placing TCP into persist mode when the network is disconnected or when losses are more as a result of high bit error. The features of ATCP are:

- End-to-end TCP semantics are intact.
- ATCP is transparent in terms of nodes with and without ATCP can set up TCP connections normally.
- ATCP’s performance is very good when measured in terms of large data transfer.
- ATCP does not interfere with TCP’s congestion control mechanism in case of network congestion.

This approach makes use of network layer feedback from intermediate hops to set the TCP sender into either persist state or congestion control state or retransmit state. This means that when network is partitioned, the TCP sender is set into persist mode so that it does not unnecessarily transmit and retransmit packets. But when packets are lost due to error instead of congestion, the TCP sender retransmits packets and does not evoke congestion control. When the network is actually congested, the TCP sender evokes congestion control. They did not modify standard TCP so that compatibility with TCP/IP networks is not affected.

In [9] Dunkels et al make effort towards making TCP/IP suitable for WSNs. They propose a novel approach for connecting WSNs to other wired networks without requiring specific proxies. This is accomplished by bringing TCP/IP to wireless sensor networks. But this is a challenging task due to sensor nodes being resource constrained in terms of limited physical size and low cost, less memory and processing power. They argue that although traditionally, these constraints have been considered too limiting for WSN to be able to implement the TCP/IP protocols. But they show in their work that even resource constrained small sized sensors can implement TCP/IP. They propose some optimizations to improve the performance of TCP/IP in WSNs. The authors identify five problem areas for which solutions are proposed: IP address assignment, TCP/IP header overhead, address centric routing, node limitations, and TCP performance in terms of energy efficiency. Their proposed solutions are: a spatial IP address assignment scheme which allows sensor nodes construct semi-unique addresses from their spatial location; joint context header compression, that takes advantage of the shared context nature of sensor networks; application overlay routing, which supports execution of data centric routing and data aggregation as application layer mechanisms; and a distributed TCP caching scheme for enhancing TCP performance and energy efficiency.

3.2.2 Parallel TCP Approaches

Iyer et al [16] take up the challenge of designing a common transport layer protocol for energy-constrained sensor networks. They present the constraints for such a transport protocol and suggest Sensor Transmission Control Protocol (STCP). This protocol is a general, scalable and reliable transport layer protocol where considerable functionality is implemented at the proxy of the gateway, which they call base station. The protocol suggests restricted variable reliability, congestion recognition and congestion avoidance, and maintains multiple applications in the same network. They evaluate protocol performance under various scenarios and network conditions. Before transmitting packets, sensor nodes establish a connection with the proxy through a "Session Initiation Packet" which notifies the proxy about number of flows originating from the node, the type of data flow, transmission rate and requisite reliability.

For continuous flows, when the proxy receives a packet from a sensor node, it calculates the estimated trip time for the packet to reach the proxy. In event-driven flows, the proxy is unable to estimate the arrival times of data packets. Sensor nodes identify the requisite reliability for each flow in the session initiation packet. For continuous flows, the proxy estimates a running average of the reliability. For event-driven flows, the proxy estimates reliability as a ratio of packets received to the highest sequence numbered packet received. STCP implements exact congestion notification with some modification. Each STCP data packet has a bit its header for congestion notification.

In [10] we presented a session-layer assisted efficient TCP management architecture for parallel TCP data transfer between Internet node and sensor nodes. Basic design elements of this architecture are

- The role of proxy is extended to session layer
- Split-TCP sessions are formed across a number of proxies
- Receiver buffer is dynamically adjusted based on link characteristics
- Two-stage flow control reflecting sensor buffer constraints at Internet node
- Independent congestion control on each TCP stream

Through mathematical analysis and simulations, it is shown in this work that data transfer through parallel split-TCP sessions outperforms single end-to-end as well single split-TCP session data transfer.

3.2.3 Protocols for WSN

An important transport layer protocol is Pump Slowly Fetch Quickly (PSFQ) which is specially designed to address the resource challenges that exist in WSNs. Data is slowly pushed from a root node into the network. Sensor nodes encountering loss can mend data segments by fetching them speedily from their direct neighbors on a hop-by-hop basis. To minimize signal overhead, nodes signal the loss of segments through negative acknowledgement, instead of acknowledging each received packet.

RMST is a reliable transport layer specifically developed for WSNs. RMST operates on top of the gradient mechanism used in directed diffusion. RMST adds two significant features to directed diffusion: fragmentation and reassembly of segments, and reliable message delivery.

ESRT (Event to Sink Reliable Transport) put forward the idea of reliable event detection from the sensor nodes to the sink. ESRT enforces the loss tolerant characteristic of WSNs, targeted to overtake a course description of the event instead of providing details.

Unlike other research work, the authors in [17] focus on bursty convergecast where important issues are reliable and real-time error control and the resulting contention control. To tackle these challenges they propose the window-less block acknowledgment scheme which enhances channel utilization and minimizes acknowledgment loss and packet delivery delay. The authors design schemes to plan packet retransmissions and to lessen timer-incurred delay, which are crucial for reliable and real-time communication of bursty traffic. They tested this approach in sensor network field experiment with deployed motes. They report that all in all the typical network as well as application models in WSNs provide chances for new methodologies in protocol engineering and are promising areas for an in-depth study.

In [18] the authors state that the network lifetime and application performance are two crucial and basic but contradictory design goals in WSNs. There is an inherent tradeoff between network lifetime optimization and application performance improvement. The application performance improvement is mostly linked to the rate at which the application can transport data reliably in these networks. They explore this tradeoff in this work by examining the connection between the network lifetime optimization problem and the rate allocation problem with a reliable data delivery goal. The authors attempted the problem from the transport layer point of view, with multi-path routing. To ensure reliable data transport they implement hop-by-hop retransmission method. They devise the network lifetime optimization and fair rate allocation as constrained optimization challenges. They distinguish the tradeoff between them, propose optimality condition, and propose a partially distributed algorithm.

In [19] Le et al propose ERTP, an Energy-efficient and Reliable Transport Protocol for Wireless Sensor Networks. ERTP is developed for data streaming applications, in which sensor readings are communicated from one or more sensor sources to a proxy or sink node. ERTP employs a statistical reliability metric which guarantees the number of data packets transported to the proxy surpasses the identified threshold. Through extensive discrete event simulations and experimental evaluations they show that ERTP is significantly more energy-efficient than other transport layer approaches and can reduce energy consumption by more than 45% when compared to other approaches.

Lee et al. [21] state that ubiquitous technology is applied to various industrial fields through sensor networks in order to improve the quality of human life. Hence one of the communications challenges to provide accurate data is a challenge in these networks. Though end-to-end data retransmission has matured as a reliable communication in wired networks like Internet, this method cannot be applied to WSNs due to the lack of reliability of wireless link and resource constrained nature of sensor nodes. In an earlier work they proposed a reliable data transfer using path-reliability and implicit ACK called RTOD on WSN. But their work lacked path reliability calculation components such as channel error rate and number of transmissions. In [paper] the authors analyze path reliability components and propose limited number of transmission method (LTM) for WSNs which is quite suitable for these networks.

It is concluded in [21] that reliable data transport is one of the most crucial requisites in wireless sensor network where different applications have different reliability requirements. The nature of WSN especially dense deployment, low processing ability, less memory and power supply provide specific design challenges at transport protocol. Therefore, assuring reliable data delivery between sensor nodes and the sink in Wireless Sensor Networks (WSN) is a difficult task. A reliable protocol in wireless sensor network is a protocol that supports data communication reliably from source to destination with acceptable packet loss. The existing problems of transport protocol are how to implement reliable data transport, congestion control and energy efficiency. The authors state that most of the existing transport protocols only provide reliable data transport or congestion control. To solve these problems, the transport layer protocols that provide both reliable data delivery and congestion control should be taken under consideration.

4. CONCLUSION

This paper presents a survey of transport layer protocols in general wired-cum-wireless and in wireless sensor networks. In this work first we elaborate problems of using time-tested TCP protocol that was specifically suited for wired networks like the Internet. The heavy protocol stack, header over-head and congestion mechanism suitable for wired links makes this protocol unsuitable for wireless networks that are characterized by low bandwidths and lossy links. The characteristics of WSN which are low cost, low power resource constrained end devices called sensor nodes very low link bandwidths and ad-hoc network topology make application of TCP even more challenging in these networks. We identify these problems in WSN and then we present the various approaches adopted by researchers in order to implement reliability in WSNs. These approaches are classified as making TCP suitable for WSN by various methods like parallel TCP, link layer retransmissions, splitting TCP across proxy, distributed TCP caching and retransmissions as well as designing new transport layer protocols for WSNs according to the features and restrictions of these networks. This survey is useful for researchers undertaking the task of exploring transport layer issues in both general wired-cum-wireless networks and specifically in WSNs.

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