Energy-Efficient Approaches in Wireless Network: A Review

Veenu Mor and Harish Kumar

Abstract Environment protection and reduction of operational cost are gaining popularity among researchers. Energy consumption has direct impact on both factors and follows an increasing trend of attentions in recent years. A number of energy-aware approaches have been found in research to trim down superfluous energy expenditure by embedding energy alertness in the protocols, devices and designing of wireless networks. This paper intends to provide a broad review of the various researches at protocol stack for minimizing energy consumption in wireless network.

Keywords Energy-efficient communication · Layer-based solutions · Cross-layer optimization

1 Introduction

Information and communication technology (ICT) plays vital role in reducing movement of people and products, to enhance efficiency of production and consumption of goods, etc. Increased use of ICT helps to reduce emissions of CO_2. But, on the other side, electricity consumption of ICT equipment itself is growing more rapidly contributing to carbon dioxide (CO_2) emission. ICT is found to be responsible for around 750 thousand tons of CO_2 production for every terawatt hour of energy dissipation. This sector is being reported to contribute for 2–3% [1] of the total CO_2 discharge of which mobile networks contribute about 0.2%. In developed countries, CO_2 emission rate is even higher. As ICT is the fastest growing sector, it can contribute significantly in enhancing energy efficiency of other sectors and hence in controlling average rise in temperatures.

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Furthermore, future trend is toward wireless communications, and bandwidth requirements are increasing with launching of new bandwidth-hungry network applications. Increasing Internet Protocol (IP) traffic demands expanding infrastructure like switches, routers and hence more network equipments are leading to energy expenditure. Hence, the need for energy-efficient solutions in network has become apparent due to the immense increase in amounts of energy consumption and carbon footprints within ICT sector. Environmental aspects and the resulting energy cost of network operators are major motivators for the energy-efficient network solutions. Additionally, compared to hardware defined approaches like power amplifiers, highly integrated modules, software-based solutions have wider scope. So, this research work focuses on review of various ongoing solutions at protocol stack.

This study broadly provides a survey of the most applicable research trends for minimizing energy expenditure in wireless networks based on protocol stack layers. The paper is formulated into four sections. Introduction to field is discussed in Sect. 1. Section 2 represents various layer-based approaches ranging from physical to application, cross-layer approach has been found to be more promising field; Sect. 3 highlights trends of research work at protocol layers over last five years; finally, Sect. 4 provides conclusion and future work.

2 Layer-Based Approaches

Energy consumption in wireless network is affected by each layers of protocol stack. Hence, energy reduction should be considered throughout all layers. Apart from traditional stand-alone solutions at individual layers, interaction among layers can further reduce energy significantly. This section focuses on classification of energy-saving techniques based on Transmission Control Protocol/Internet Protocol (TCP/IP) protocol stack as depicted in Fig. 1. Application layer occupies top of stack followed by transport, network, data link, and physical layer.

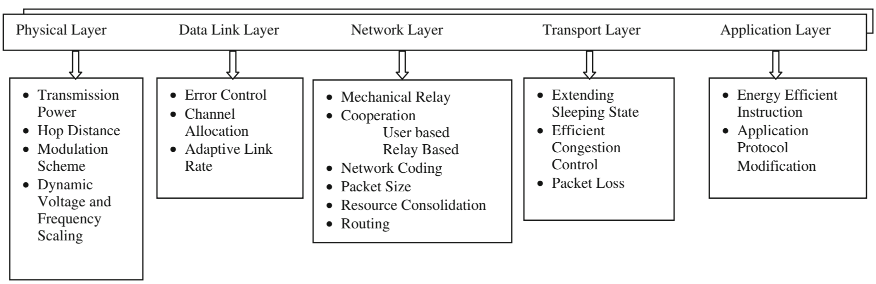

Fig. 1 Energy-efficient approaches at various layers of TCP/IP protocol stack

2.1 Physical Layer

Physical layer is accountable for real conduction of data over communication link in signal forms. Energy efficiency at physical layer can be achieved by optimal setup of various parameters like transmit power, hop distance, modulation scheme, dynamic voltage/frequency scaling. These parameters further depend on type of channel models like Gaussian noise, block Rayleigh fading.

Transmission Power: It determines coverage area, effecting chances of locating the receiver. Signal-to-noise ratio of the channel decides successful decoding of received transmission and is proportional to transmission power. Increases in transmission power decrease likeliness of error and enhance the chance of successful transmission. But on other front leads to higher probability of collision with other transmissions in neighbor. Hence, to achieve energy-efficient successful transmission, an optimal balance between the two needs to strike out. In [2], performance with respect to variable transmission power of a multi-hop network has been analyzed. Energy of beam-forming base stations is reduced significantly at cost of minor increase in consumption at user end. [3] has evaluated performance of variable transmission power control on energy, delay, throughput, etc., which shows better results for network performance and energy saving than common-range transmission control schemes.

Hop distance: On similar ground, optimal hop distance helps in minimizing per packet expended energy across a multi-hop network. It is based on rule that increase in hop distance increases chances of error, hence increases power consumption while reduces fixed circuitry cost due to less number of reception and transmission (due of less number of hops) and vice versa.

Modulation: It is a deciding factor for the probability of success of transmission as well as to achieve energy-efficient communication. Rosas and Oberli [4] have studied optimization of modulation size with respect to Signal-to-Interference-plus-Noise Ratio (SINR). It is reported that every modulation is associated with an optimum SINR value where energy consumption for one bit of data can be found to be minimum. In this scenario, binary phase shift keying and quadrature phase shift keying are the optimum options for high transmission distances. But with decrease in transmission distance, the optimal modulation size can be as high as 64-quadrature amplitude modulation (QAM). This study is based on an error-free environment for both backward and forward frames, i.e., ignore possibility of loss of data, and energy consumed at transmission and receiving are assumed to be equal. Whereas [5] has optimized the M-ary QAM constellation size in multi-hop linear networks with goal of minimizing the energy used per bit with in average bit error rate. Modulation size and routing paths are together optimized. The circuit, transmission, and retransmission energies have been considered. While, in [6], modulation scheme has achieved energy performance by dipping total of packet retransmission and hence the amount of bits.

Dynamic Voltage/Frequency Scaling (*DVFS*): Physical layer can also handle processors and radio parameters as per ongoing working environment. By utilizing multiple voltages and frequency levels, energy eating can be reduced significantly. The voltage and clock frequency can be varied based on workload to meet preferred performance with minimum energy expenditure [6, 7]. It is one of the most useful techniques when low-power sleep is not an alternative. A number of work are found in the literature on DVFS, and approaches which work equally well in regular and irregular workload needs more attention.

Being closer to physical medium among all layers, physical layer has vital role in energy-efficient solutions, but network components may have varying properties. So building solutions at physical layer involve separate solutions for such different components.

2.2 Data Link Layer

Data Link layer (DDL) has potential to achieve energy-efficient operation. Error control, channel allocation, and adaptive link rate (ALR) have been identified as key components.

Error control: Significant number of studies has been reported on error control at logical link part of DDL. It can be achieved by error coding, e.g., forward error correcting (FEC) [8] and retransmission, e.g., automatic repeat request (ARQ) [9, 10]. FEC is a way to control errors of data transmission. Sender appends error-correcting code to original messages, whereas ARQ deals with errors through retransmission. In view of ARQ, utilizing current state of network conditions can help in making decisions in re-transmitting packets at favorable time and hence achieve energy savings. In [9, 10], transmitter nodes make intelligent decision to reduce retransmissions by utilizing channel quality information for achieving energy reductions.

Channel Allocation: Channels are scarce resource in wireless communication and must be allocated efficiently throughout network. Channel allocation can be achieved at media access control (MAC), and being an important parameter, it can contribute significantly in archiving energy-efficient communications. An energy-efficient MAC scheme should utilize benefit from both traffic and network characteristics. Channel access MAC approaches can be majorly classified into three types, i.e., contention-based, conflict-free, and hybrid. The contention-based approaches cover channel allocations using ALOHA, slotted ALOHA, carrier sense multiple access (CSMA), CSMA/CD, CSMA/CA, whereas FDMA, TDMA, FH-CDMA, DS-CDMA are conflict-free. PRMA and D-TDMA are part of hybrid channel allocation approaches. Numeral research works have been reported in the literature with green channel allocation strategy. For instance, Wu et al. [11] have jointly addressed both power and multi-channel issues to achieve energy efficiency at a node by controlling the transmit power to reach intended receiver during transmission. But this power control approach is found more effective when numbers of channels are lesser than a threshold. Misra et al. [12] have introduced learning automata-based distributed dynamic channel allocation approach with a focus toward improving overall system performance by reducing dropping probability in a highly mobile scenario. It helps to achieve energy saving but study lacks in experimenting with different mobility patterns. In [13], energy-efficient MAC (EE-MAC) for ad hoc protocol without significantly reducing network performance is proposed. This approach is based on principle idea of electing some nodes to form a connected virtual backbone set to route packets, while other nodes named as slaves can stay in power-saving mode. Sheelavant and Sumathi [14] have proposed a channel interference limited routing protocol for delay sensitive traffic to meet throughput increase and energy saving of cognitive radio sensor networks. In [15], two energy-efficient strategies, namely altruistic DISH, in situ DISH for cooperative multi-channel MAC Protocols have been proposed. Approach is applicable for single radio per node and does not require time synchronization. Results demonstrate 40–80% energy saving without compromising at throughput part. But, in situ is found suitable for scenario with less density nodes or low traffic.

In wide, purpose of energy-efficient channel allocation is to limit packets collision for efficient channel utilizations and hence energy resource.

Adaptive Link Rate: It is an energy proportional computing scheme, which adopts data rate with objective of optimum performance and energy efficiency depending on traffic or channel conditions. It has less complex physical layer modulation so needs less-power consumption to decode. A variable data rate scheme is used in [16] to optimize total communication energy in body sensor network and wifi. It achieves 86% energy reduction with respect to fixed data rates solution. Furthermore, Nedevschi et al. [17] have proposed an energy-saving policy for link rate adaptation based on link utilization and buffer queue length. Results are compared with link sleep policy and found that during low link utilization, sleep state is more feasible than rate adaption.

As seen, DDL has good capability toward achieving energy-efficient networking. Adding mobility awareness in this layer will help in recovery of data due to path failure.

2.3 Network Layer

In wireless mobile networks, the network layer is accountable for routing packets under mobility constraints. Apart from traditional routings approaches, following techniques can be applied to achieve energy efficiency at this layer.

Mechanical Relaying (*Store and Forward*): It is a technique applicable in wireless mobile networks where communication is intentionally delayed till meeting favorable networking conditions (e.g., improved SINR, region of less prone to error). Mobile nodes can act as relay to carry data of its own and others node. They are facilitated with ability to store information while on move. Hence, in mechanical relay (MR), mobile nodes operate under a store-carry and forward paradigm [18, 19]. Transmitting at better locations allows efficient use of radio by reducing transmit power. It also leads to less interference to other nodes and hence better SINR at receiver side. Hence, this feature of carrying data mechanically, communicating only at the best locations and within delivery deadlines helps to achieve significant reduction in energy consumption during transmission. Kolios et al. [20] proposed a MR to solve the problem of energy efficiency in cellular network and proved that mobility prediction can be beneficial in saving energy. But study is only limited to single cell, hence lacking intra-cell communication. Message forwarding decision policy and size of message are key factors for successful energy-efficient transmission. Policy can be applied in centralized or distributed, or hybrid manner. Cross-layer approach at application and MR at network layer can together achieve further performance gains.

Energy Efficiency with Cooperation: Utilization of cooperation between nodes of the network is one of successful technique to reduce energy consumption and to achieve better performance improvement of wireless transmission [21, 22]. Cooperation can be categorized into two types, first is relay cooperation (RC) [21], in which relay nodes assist the source in transmitting information to destinations, and second is user cooperation(UC) [22] which is more suitable in multicast scenario. UC is based on concept that destinations which receive data successfully and have better channel quality to other destination nodes than source node will further assist source in transmitting data to other remaining destinations. RC and UC both can decrease the total energy consumption of network. But RC requires installation of new relay node to network, hence expensive than UC. In UC, user's relay nodes may not always have better link quality with the remaining users than source node. Performance is not always assured in UC.

Energy Efficiency with Network Coding: Under this approach, router nodes mix content of different packets and broadcast the resulting packets. Network coding (NC) helps to achieve optimum usage of network resources. Hence, it is important to explore its effect on energy-efficient systems. Chen et al. [23] have shown that by applying NC bandwidth can be saved. It is more suitable for multicasting scenario. Chen et al. [24] have evaluated the potential of coding from perspective of throughput and energy efficiency. Energy-saving factor in unicast random networks is upper limited by 3, while throughput is lower bounded by a constant factor, but it is suspected that the constant factor can be even smaller. Blind flooding factor for achieving broadcast in NC can be improved by utilizing better broadcast mechanism. Keeping this in view, [25] has combined NC with connected dominating set (CDS)-based broadcasting approach to give network coding over connected dominating set (NCDS). Energy gains have been reported as 161% over blind flooding and 37% over CDS. In [26], network coding-based probabilistic routing scheme has been projected. Results of scheme in terms of energy efficiency and reliability have been found better than probabilistic routing and pure flooding.

Packet Size: It has relationship with loss probability and provides valuable information in adjusting different network conditions for optimum utilization of wireless resources [27]. Probability of packet delivery increases with small packets achieving energy efficiency. But when overhead bits are taken into account, highest energy efficiency exists for some optimal packet size [28]. In [29], packet size optimization is devised as a nonlinear constrained problem, solved with sequential quadratic programming. In [30], the packet size and transmission power are decided as a function of distance between transmitter and receiver under varying modulation strategy. Data compression reduces transmission time of packets by reducing transmitted bits; it can be looked as a firm technique for energy reduction and can be applied at packet payload [31] and header part [32]. Additional computation cost incurred by data compression needs to be considered for energy saving. [33] has proposed a simple low computation power hungry algorithm.

Resource Consolidation: Networks are deployed keeping in view the quality of service for peak traffic demands. In scenario when traffic follows a pattern on periodical basis [34], resources are over-provisioned during low traffic periods. Networks need not to operate in full capacity and can be dynamically adjusted according to current traffic level. Resource consolidation (RC) is a kind of routing achieves this objective by consolidating the network load and traffic on a selected set of active network nodes and shutting down other lightly loaded nodes. Load is redistributed by cooperation among network equipment [35]. RC is an attractive means in fields like data centers, CPU, wired networks.

2.4 Transport Layer

Transport layer provides service for end-to-end communication. TCP/IP stack has been proposed keeping in view of wired connections. Performance of classical transport protocols degrades considerably in wireless network. It is necessary to consider energy efficiency behavior of the transport layer protocols. Extending sleeping state, efficient congestion control, packet loss recoveries are few of approaches which can be exploited under this layer.

Extending Sleeping State: Such, approaches control data traffic to achieve maximum sleep period. Few of early work has been addressed in [36–38]. In [36], energy/throughput trade-off of TCP has been considered. In [37], energy consumption for bulk data transfer under different TCP versions like Tahoe, Reno, and New Reno has been studied. In [38] TCP header has been modified for TCP sleep option. Before sleeping, client notifies server through this option. On seeing TCP sleep from client, server will store data received from the application and does not send it immediately. In [39], energy consumption of TCP data transfer by stretching the ideal period has been considered. Bursty communication over a wireless LAN can reduce the energy expenditure in TCP data transmit by around 60%. But analysis of energy saving with impact over delay has been ignored. Hu and Li [40] have studied cross-layer-based approach for energy competence of TCP in wireless cooperative relaying networks. Relay selection is solved by using primal-dual index-based heuristic algorithm. It is shown that the energy efficiency of TCP can be enhanced by adapting the lower layer parameter, e.g., modulation, coding, frame length, and limit on retransmission time.

Efficient Congestion Control and Packet Loss: Congestion can occur if packet arrival rate exceeds packet service layer. Factors like contention, bit error, interference contribute toward packet loss and also add to congestion. In all both factors increase packet service time and degrade energy performance. They are as such important factors to be dealt under this layer. Suitable rate adjustment and retransmission techniques will help to mitigate this issue. In [41], adaptive duty cycle-based congestion control scheme has been projected.

Research for achieving energy efficiency is more centered toward lower layers; upper layers had been ignored. Further potential of transport layer for energy-efficient solutions needs to be explored for maximal gain in this direction.

2.5 Application Layer

Application layer consists of high-level setup services for the application program and acts as interface between user and network. As being most closed to end user, this layer is the best choice for utilizing application-specific information toward designing energy-efficient solutions.

Application Protocol Modification: Energy saving can be achieved by modifying particular application protocol and utilizing traffic pattern knowledge. For instance, existing Bit Torrent, a P2P technology, used in distribute digital content in decentralized architecture requires peers to be active all the time in spite of current load. Green BitTorrent [42] is an improved version of existing BitTorrent, which allows clients sleep in a swarm by disconnecting their TCP connections with peers when not actively downloading or uploading contents, yet still active member in peer lists. An assessment of Green BitTorrent with respect to energy savings and download time has been done. Energy savings of up to 25% with standard version are realizable, but with small increase in file download time. For backwards compatibility with existing BitTorrent method to signal type of peer, i.e., green or nongreen and to wake up the sleeping clients are not mentioned. From protocol modification perspective, [43] Telnet is redesigned with a green objective to give Green Telnet Protocol, allowing the client to go to sleep and recover later. Additional control messages are required to share power state changes to avoid losing data.

Energy-Efficient Instructions: It is other tool for achieving this goal, some work toward this direction has been presented in [44, 45]. In [44], a green framework has been proposed that supports energy-conscious programming using principled approximation for expensive loops and functions. A dynamic instruction scheduling logic has been discussed in [45]. It is based on grouping a number of instructions as a single dispatch entity. The proposed logic holds and sends off extra instructions without growing the size or number of ports. The results show energy cutback of 42, 50, and 44% for dispatch, select, and issue correspondingly. Green programming can be explored further for reducing programmer burden through more automated program approximation.

Energy-saving process can involve cross-layer cooperation as power consumption is affected by each aspects of system design, varying from hardware to applications. Parameters of multiple layers like transmit powers, rates, link schedules, routing can be utilized for joint optimization objective across protocol stack with adjustability to required service, traffic load, and surroundings dynamics. A large number of different issues have been successfully addressed by cross-layer approaches in networking. Cross-layer solution can be seen as a very promising research area in field of energy saving [46].

3 Trends

A survey on IEEE Xplore for last five years has been carried out to find out the popularity of research in energy efficiency of TCP/IP protocol stack, and recorded observations have been listed in Table 1. The following query has been used on abstract, which is further refined by publication date and including discussed layerwise approaches. Though, results may vary with inclusion/exclusion of other keywords. The outcome clearly indicates that in energy-efficient wireless communication overall research trend is increasing.

> Abstract (((((Energy OR Green) AND (Efficiency OR Efficient OR Saving OR Aware OR Conservation OR Harvesting OR Performance OR Computing OR Communication OR Radio OR Modulation OR Performance OR Consumption)) AND Wireless Network))

Table 1 Trend in IEEE Xplore over last five years

Layer year	2011 (Jan–Dec)	2012 (Jan–Dec)	2013 (Jan–Dec)	2014 (Jan–Dec)	2015 (Jan–Aug)	Total
Physical layer	123	145	133	160	78	639
Data link layer	86	74	112	108	53	433
Network layer	483	520	493	486	210	2191
Transport layer	74	78	71	62	26	311
Application layer	8	13	8	13	1	43
Total	1583	1686	1730	1742	788	7528

4 Conclusion and Future Work

This study has highlighted solutions toward energy reduction within each layer of TCP/IP protocol stack. The overall energy consumption is influenced by the functionality of each layer. Future road map requires more coordinated energy control among all layers with due consideration toward energy consumption of solution itself. Based on survey, it has been acknowledged that inclination of research is increasing in energy efficiency. Functionality of network layers are most explored one in achieving energy-efficient solutions, and application layer is least targeted. Hence, being most closed to end user, there is plenty of scope of research for achieving energy efficiency at application layer.

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