Module 5: Quality of Service in Ad Hoc Wireless Networks

Introduction

- Quality of service (QoS) is the performance level of a service offered by the network to the user. The goal of QoS provisioning is to achieve a more deterministic network behavior, so that information carried by the network can be better delivered and network resources can be better utilized.
- A network or a service provider can offer different kinds of services to the users. Here, a service can be characterized by a set of measurable prespecified service requirements such as minimum bandwidth, maximum delay, maximum delay variance (jitter), and maximum packet loss rate.

Issues and Challenges in Providing Qos in Ad Hoc Wireless Networks

- **Dynamically varying network topology:** Since the nodes in an ad hoc wireless network do not have any restriction on mobility, the network topology changes dynamically. Hence, the admitted QoS sessions may suffer due to frequent path breaks.

- **Imprecise state information:** In most cases, the nodes in an ad hoc wireless network maintain both the link-specific state information and flow-specific state information. The link-specific state information includes bandwidth, delay, delay jitter, loss rate, error rate, stability, cost, and distance values for each link.The flow-specific information includes session ID, source address, destination address, and QoS requirements of the flow.

- **Lack of central coordination:** Unlike wireless LANs and cellular networks, ad hoc wireless networks do not have central controllers to coordinate the activity of nodes. This further complicates QoS provisioning in ad hoc wireless networks.

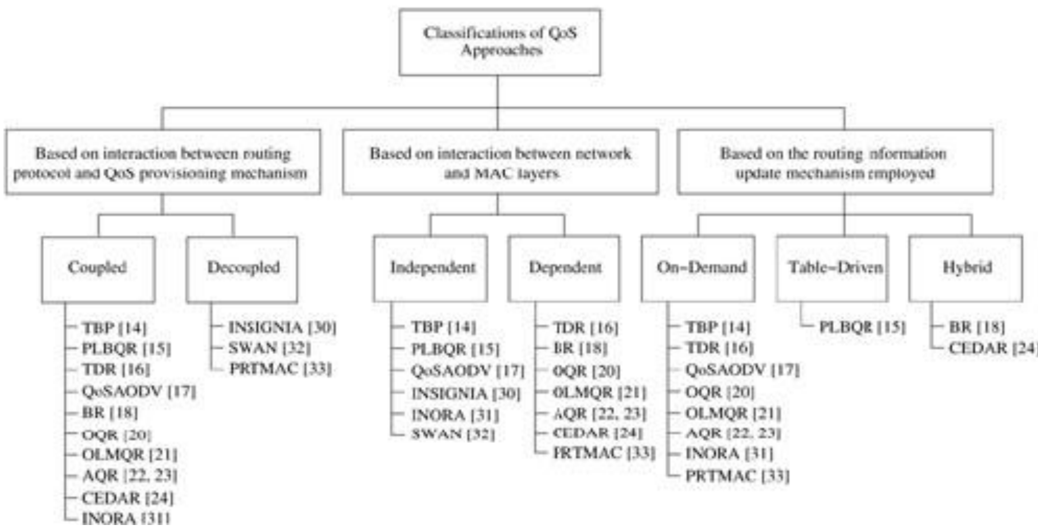
- **Error-prone shared radio channel:** The radio channel is a broadcast medium by nature. During propagation through the wireless medium, the radio waves suffer from several impairments such as attenuation, multipath propagation, and interference.

- **Hidden terminal problem:** The hidden terminal problem is inherent in ad hoc wireless networks. This problem occurs when packets originating from two or more sender nodes, which are not within the direct transmission range of each other, collide at a common receiver node. It necessitates the retransmission of the packets, which may not be acceptable for flows that have stringent QoS requirements.

- **Limited resource availability:** Resources such as bandwidth, battery life, storage space, and processing capability are limited in ad hoc wireless networks. Out of these, bandwidth and battery life are critical resources, the availability of which significantly affects the performance of the QoS provisioning mechanism. Hence, efficient resource management mechanisms are required for optimal utilization of these scarce resources.

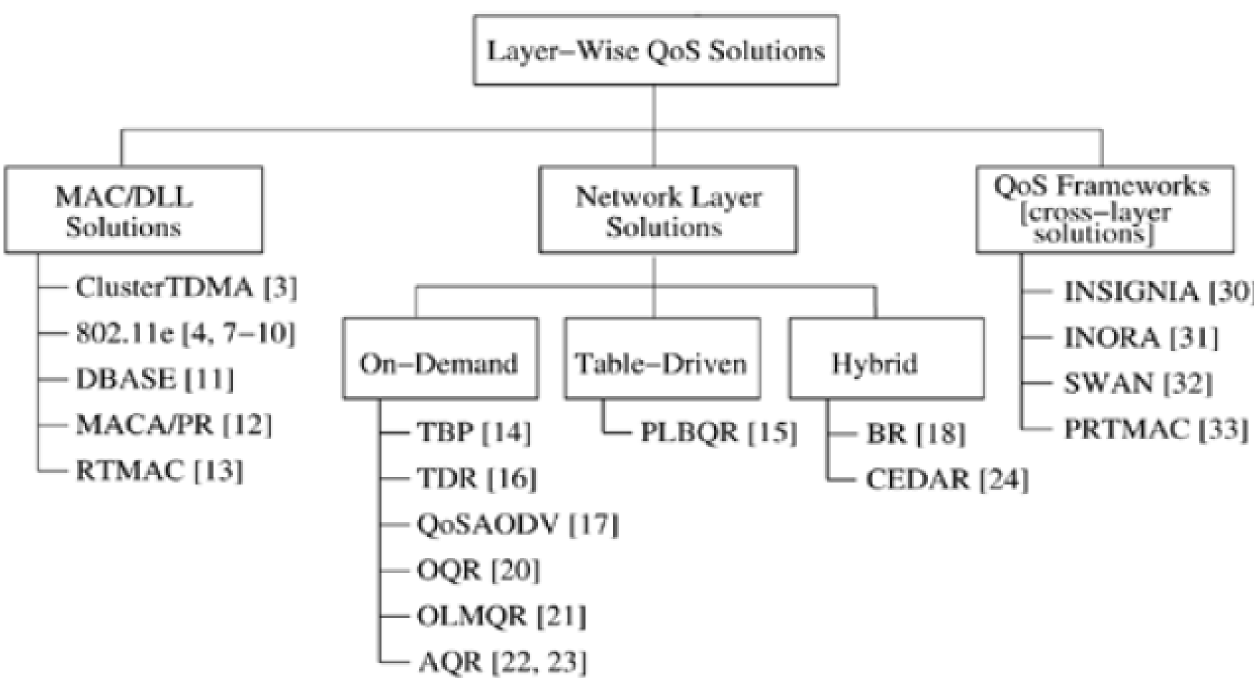
- **Insecure medium:** Due to the broadcast nature of the wireless medium, communication through a wireless channel is highly insecure. Therefore security is an important issue in ad hoc wireless networks, especially for military and tactical applications.

Figure 10.2. Classifications of QoS approaches.



Layer-Wise Classification of Existing QoS Solutions

The existing QoS solutions can also be classified based on which layer in the network protocol stack they operate in



Layer-wise classification of QoS solutions

MAC LAYER SOLUTIONS

The MAC protocol determines which node should transmit next on the broadcast channel when several nodes are competing for transmission on that channel. The existing MAC protocols for ad hoc wireless networks use channel sensing and random back-off schemes, making them suitable for best-effort data traffic. Real-time traffic (such as voice and video) requires bandwidth guarantees. Supporting real-time traffic in these networks is a very challenging task.

Cluster TDMA

- Cluster TDMA is proposed for supporting real-time traffic in ad hoc wireless networks. In bandwidth-constrained ad hoc wireless networks, the limited resources available need to be managed efficiently. To achieve this goal, a dynamic clustering scheme is used in Cluster TDMA.
- In this clustering approach, nodes are split into different groups. Each group has a cluster-head (elected by members of that group), which acts as a regional broadcast node and as a local coordinator to enhance the channel throughput.
- Every node within a cluster is one hop away from the cluster-head. The formation of clusters and selection of cluster-heads are done in a distributed manner.
- Clustering algorithms split the nodes into clusters so that they are interconnected and coverall the nodes.
- Three such algorithms used are lowest-ID algorithm, highest degree algorithm, and least cluster change (LCC) algorithm.
- In the lowest-ID algorithm, a node becomes a cluster-head if it has the lowest ID among all its neighbors.
- In the highest-degree algorithm, a node with a degree greater than the degrees of all its neighbors becomes the cluster-head.
- In the LCC algorithm, cluster-head change occurs only if a change in network causes two cluster-heads to come into one cluster or one of the nodes moves out of the range of all the cluster-heads.

In most cases, ad hoc wireless networks share a common radio channel operating in the ISM band2 or in military bands. The most widely deployed medium access technology is the IEEE 802.11 standard. The 802.11 standard has two modes of operation: a distributed coordination function (DCF) mode and a point coordination function (PCF) mode. The DCF mode provides best-effort service, while the PCF mode has been designed to provide real-time traffic support in infrastructure-based wireless network configurations. Due to lack of fixed infrastructure support, the PCF mode of operation is ruled out in adhoc wireless networks.

Distributed Coordination Function

In the DCF mode, all stations are allowed to contend for the shared medium simultaneously. CSMA/CA mechanism and random back-off scheme are used to reduce frame collisions. Each unicast frame is acknowledged immediately after being received. If the acknowledgment is not received within the timeout period, the data frame is retransmitted. Broadcast frames do not require acknowledgments from the receiving stations. If a station *A* wants to transmit data to station *B*, station *A* listens to the channel. If the channel is busy, it waits until the channel becomes idle. After detecting the idle channel, station *A* further waits for aDIFS period and invokes a back-off procedure.
The back-off time is given by

$$\mathrm{Back-off\ Time} = rand(0, CW) \times slottime$$

where *slot time* includes the time needed for a station to detect a frame, the propagation delay, the time needed to switch from the receiving state to the transmitting state, and the time to signal to the MAC layer the state of the channel. The function *rand* (0, *CW*) returns a pseudo-random integer from a uniform distribution over an interval [0, *CW*].

Point Coordination Function

The IEEE 802.11 standard incorporates an optional access method known as PCF to let stations have priority access to the wireless medium. This access method uses a point coordinator (PC), which operates at an AP. Hence PCF is usable only in infrastructure-based network configurations. A station which requires the PCF mode of operation sends an association message to the PC to register in its polling list and gets an association identifier (AID). The PC polls the stations registered in its polling list in ascending order of AIDs to allow them contention-free access to the medium. The role of the PC is to determine which station should gain access to the channel. The stations requesting the PCF mode of operation get associated with the PC during the contention period (CP). With PCF, the channel access alternates between the contention free period (CFP) and the contention period (CP) for the PCF and DCF modes of operation, respectively.

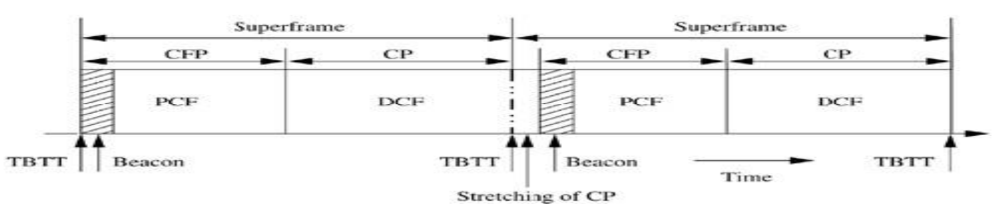
A CFP and the following CP form a super frame. The PC generates a beacon frame at regular beacon frame intervals called target beacon transmission time (TBTT). The value of TBTT is announced in the beacon frame. Each super frame starts with a beacon frame, which is used to maintain synchronization among local timers in the stations and to deliver protocol related parameters.

Figure 10.4 shows the operation of the network in the combined PCF and DCF modes. The channel access switches alternately between the PCF mode and the DCF mode, but the CFP may shrink due to stretching when DCF takes more time than expected.

PCF has certain shortcomings which make it unsuitable for supporting real-time traffic.

NETWORK LAYER SOLUTIONS

Figure 10.4. PCF and DCF frame sharing.



The bandwidth reservation and real-time traffic support capability of MAC protocols can ensure reservation at the link level only, hence the network layer support for ensuring end-to-end resource negotiation, reservation, and reconfiguration is very essential. Xet section describes the protocols provided by network layer

Ticket-Based QoS Routing Protocol:

Ticket-based QoS routing is a distributed QoS routing protocol for ad hoc wireless networks.

This protocol has the following features:

- It can tolerate imprecise state information during QoS route computation and exhibits good performance even when the degree of imprecision is high.
- It probes multiple paths in parallel for finding a QoS feasible path. This increases the chance of finding such a path. The number of multiple paths searched is limited by the number of tickets issued in the probe packet by the source node.

- State information maintained at intermediate nodes is used for more accurate route probing. An intelligent hop-by-hop selection mechanism is used for finding feasible paths efficiently.

- The optimality of a path among several feasible paths is explored. A low-cost path that uses minimum resources is preferred when multiple feasible paths are available.

Protocol Overview

- The basic idea of the ticket-based probing protocol is that the source node issues a certain number of tickets and sends these tickets in probe packets for finding a QoS feasible path.

- Each probe packet carries one or more tickets. Each ticket corresponds to one instance of the probe. For example, when the source node issues three tickets, it means that a maximum of three paths can be probed in parallel.

- The number of tickets generated is based on the precision of state information available at the source node and the QoS requirements of the connection request. If the available state information is not precise or if the QoS requirements are very stringent, more tickets are issued in order to improve the chances of finding a feasible path.

- If the QoS requirements are not stringent and can be met easily, fewer tickets are issued in order to reduce the level of search, which in turn reduces the control overhead. There exists a trade-off here between the performance of the QoS routing protocol and the control overhead

Predictive Location-Based QoS Routing Protocol

- The predictive location-based QoS routing protocol (PLBQR) [15] is based on the prediction of the location of nodes in ad hoc wireless networks.
- The prediction scheme overcomes to some extent the problem arising due to the presence of stale routing information. No resources are reserved along the path from the source to the destination, but QoS-aware admission control is performed.
- The network does its best to support the QoS requirements of the connection as specified by the application.
- The QoS routing protocol takes the help of an update protocol and location and delay prediction schemes.
- The update protocol aids each node in broadcasting its geographic location and resource information to its neighbors. Using the update messages received from the neighbors, each node updates its own view of the network topology.
- The update protocol has two types of update messages, namely, Type 1 updateand Type 2 update. Each node generates a Type 1 update message periodically. A Type 2 update message is generated when there is a considerable change in the node's velocity or direction of motion.
- From its recent update messages, each node can calculate an expected geographical location where it should be located at a particular instant and then periodically checks if it has deviated by a distance greater than ä from this expected location. If it has deviated, a Type 2 update message is generated.

Location and Delay Predictions

In establishing a connection to the destination D, the source S first has to predict the geographic location of node D and the intermediate nodes, at the instant when the first packet reaches the respective nodes. Hence, this step involves location prediction as well as propagation delay prediction. The location prediction is used to predict the geographic location of the node at a particular instant tf in the future when the packet reaches that node. The propagation delay prediction is used to estimate the value of tf used in the above location prediction. These predictions are performed based on the previous update messages received from the respective nodes.

Location Prediction

Let (x1 , y1) at t1 and (x2 , y2) at t2 (t2 > t1) be the latest two updates from the destination D to the source node S. Assume that the second update message also indicates v, which is the velocity of D at (x2 , y2). Assume that node S wants to predict the location (xf, yf) of node D at some instant tf in the future. This situation is depicted in Figure 10.9. The value of tf has to be estimated first using the delay prediction scheme, which will be explained later in this section. From Figure 10.9, using similarity of triangles, the following equation is obtained:

$$\frac{y_2 - y_1}{y_f - y_1} = \frac{x_2 - x_1}{x_f - x_1} \quad \text{.........10.5.1}$$

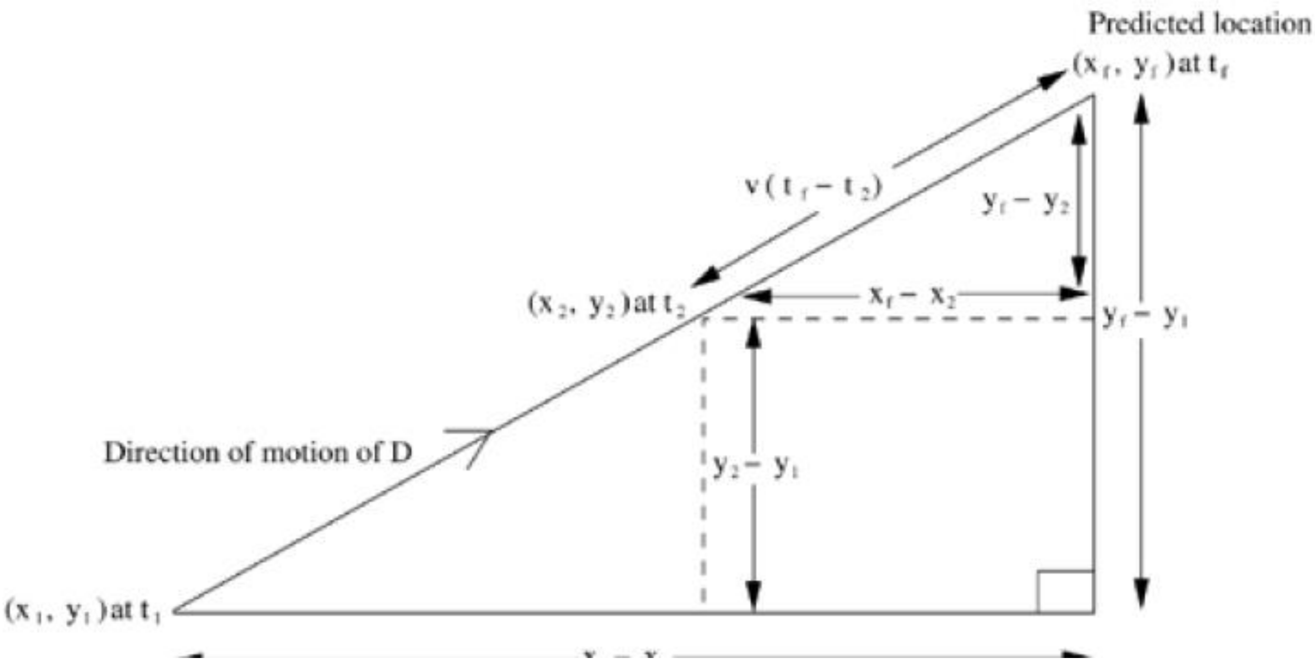


Figure 10.9. Prediction of location at a future time by node S using the last two updates.

By solving the above equation for *yf*

$$y_f = y_1 + \frac{(x_f - x_1)(y_2 - y_1)}{x_2 - x_1} \quad \text{.........10.5.2}$$

Using the above Equation 10.5.2, source *S* can calculate *yf* if it knows *xf* , which in turn can be calculated as follows. Using similarity of triangles again, the following equation is obtained:

$$y_f - y_2 = \frac{(y_2 - y_1)(x_f - x_2)}{x_2 - x_1} \quad \text{........10.5.3}$$

By using the Pythagorean theorem,

$$(x_f - x_2)^2 + (y_f - y_2)^2 = v^2(t_f - t_2)^2 \quad \text{...........10.5.4}$$

Substituting for *yf* - *y*2 from Equation 10.5.3 in the above Equation 10.5.4 and solving for *xf* , the following equation is obtained:

$$x_f = x_2 + \frac{v(t_f - t_1)(x_2 - x_1)}{\sqrt{[(x_2 - x_1)^2 + (y_2 - y_1)^2}} \quad \text{.......10.5.5}$$

QoS-Enabled Ad Hoc On-Demand Distance Vector Routing Protocol

- Perkins *et al.* have extended the basic ad hoc on-demand distance vector (AODV) routing protocol to provide QoS support in ad hoc wireless networks. To provide QoS, packet formats have been modified in order to specify the service requirements which must be met by the nodes forwarding a *RouteRequest* or a *RouteReply*.
- QoS Extensions to AODV Protocol Several modifications have been carried out for the routing table structure and *RouteRequest* and *RouteReply* messages in order to support QoS routing. Each routing table entry corresponds to a different destination node.
- The following fields are appended to each routing table entry:

• Maximum delay
• Minimum available bandwidth
• List of sources requesting delay guarantees
• List of sources requesting bandwidth guarantees

NEED FOR ENERGY MANAGEMENT IN AD HOC WIRELESS NETWORKS

The energy efficiency of a node is defined as the ratio of the amount of data delivered by the node to the total energy expended. Higher energy efficiency implies that a greater number of packets can be transmitted by the node with a given amount of energy reserve. The main reasons for energy management in ad hoc wireless networks are listed below:

• **Limited energy reserve:** The main reason for the development of ad hoc wireless networks is to provide a communication infrastructure in environments where the setting up of a fixed infrastructure is impossible. Ad hoc wireless networks have very limited energy resources. Advances in battery technologies have been negligible as compared to the recent advances that have taken place in the field of mobile computing and communication. The increasing gap between the power consumption requirements and power availability adds to the importance of energy management.

• **Difficulties in replacing the batteries:** Sometimes it becomes very difficult to replace or recharge the batteries. In situations such as battlefields, this is almost impossible. Hence, energy conservation is essential in such scenarios.

• **Lack of central coordination:** The lack of a central coordinator, such as the base station in cellular networks, introduces multi-hop routing and necessitates that some of the intermediate nodes act as relay nodes. If the proportion of relay traffic is large, then it may lead to a faster depletion of the power source for that node. On the other hand, if no relay traffic is allowed through a node, it may lead to partitioning of the network. Hence, unlike other networks, relay traffic plays an important role in ad hoc wireless networks.

• **Constraints on the battery source:** Batteries tend to increase the size and weight of a mobile node. Reducing the size of the battery results in less capacity which, in turn, decreases the active lifespan of the node. Hence, in addition to reducing the size of the battery, energy management techniques are necessary to utilize the battery capacity in the best possible way.

• **Selection of optimal transmission power:** The transmission power selected determines the reachability of the nodes. The consumption of battery charge increases with an increase in the transmission power. An optimal value for the transmission power decreases the interference among nodes, which, in turn, increases the number of simultaneous transmissions.

• **Channel utilization:** A reduction in the transmission power increases frequency reuse, which leads to better channel reuse. Power control becomes very important for CDMA-based systems in which the available bandwidth is shared among all the users. Hence, power control is essential to maintain the required signal to interference ratio (SIR) at the receiver and to increase the channel reusability.

Classification of Energy Management Schemes

The need for energy management in ad hoc wireless networks, discussed in the previous section, points to the fact that energy awareness needs to be adopted by the protocols at all the layers in the protocol stack, and has to be considered as one of the important design objectives for such protocols.

Energy conservation can be implemented using the following techniques:

• Battery management schemes
• Transmission power management schemes
• System power management schemes

Maximizing the life of an ad hoc wireless network requires an understanding of the capabilities and the limitations of energy sources of the nodes. A greater battery capacity leads to a longer lifetime of the nodes. Increasing the capacity of the batteries can be achieved by taking into consideration either the internal characteristics of the battery (battery management) or by minimizing the activities that utilize the battery capacity (power management). The system power management approach can be further divided into the following categories:

• Device management schemes
• Processor power management schemes

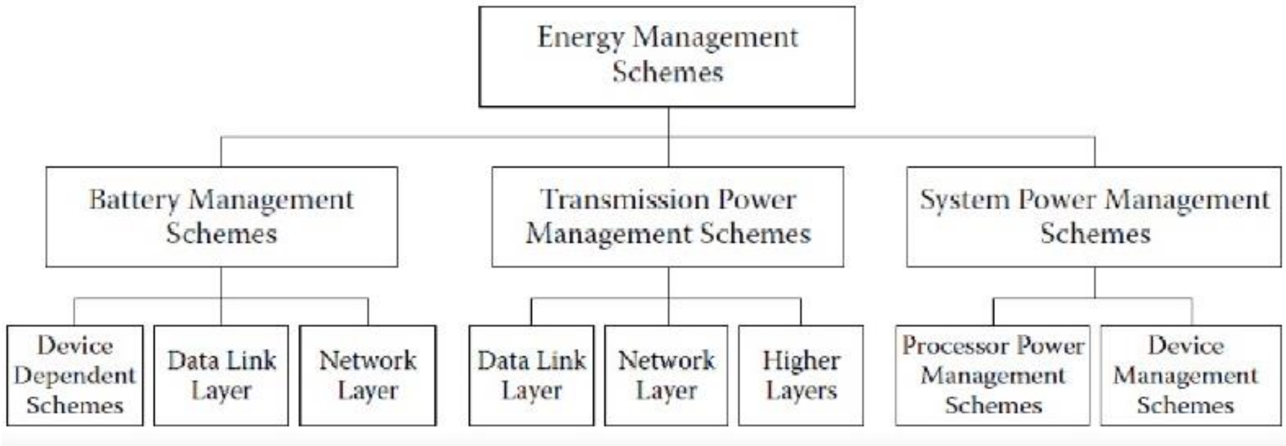


Fig 1 Classification of Energy Management Schemes