Chapter 2
Literature Survey

2.1 Cross-Layer Design

Mobile ad-hoc networking is a cross-layer problem where a variety of physical and medium access layer parameters are put together in natural process with functions of the transport and routing layers. Moreover, state information related to a selected layer becomes out there across layers as sure functions may take pleasure in that data. The physical and access layer functions is represented as $I(t)$ embody power management and channel allocation, wherever the latter corresponds to carrier and frequency choice in Orthogonal Frequency Division Multiplexing (OFDM), unfolding code and rate adjustment in spread spectrum, yet as slot allocation in TDMA systems. The physical layer needs to adapt to speedy changes in link characteristics. Such as, the multiple access management layers has to minimize collisions, permit honest access and semi-reliably transport knowledge over the shared wireless links within the presence of speedy changes and hidden or exposed terminals. The network layer has to verify and distribute data accustomed calculate ways during a means that maintains potency once links modification typically and information measure is at a premium. Owing to the interference properties of wireless communication, the communication links between pairs of nodes in wireless atmosphere cannot be viewed severally, however, rather as interacting entities wherever the bit rate of one could be a perform of decisions for the physical and access layer parameters of the others. After analysis of what information can be shared among the layers, it was seen that sensed topology information is the important information to support cross-layer design in wireless ad-hoc networks. Sensed topology information in Table 2.1 includes channel and link condition, geometric location, and so on. This information may be exchanged through interface to get better network performance. There is high mobility and rapid deployment of the mobile nodes.

Hence, there is need for multi-hop transmission where nodes can forward other nodes information. A cross-layer design allows interaction between the layers above or below it. The strict layered architecture may not be the best model for wireless network. It is difficult to optimize the network performance according to different situation without interaction among the different layers. In dynamic network, there is a need for different layers to cooperate closely to meet QoS requirements of the mobile application. This goal can be achieved when the routing layer share the link quality information and channel bandwidth information of the MAC layer. For making decision, the same information may be used by different layers like the link and channel state, topology information, and location for the nodes are used by the routing and application layers to compute routes. The layered protocol stack does not function efficiently in mobile wireless environment. To improve the performance of these protocol stacks, there is a need for cross-layer feedback. Cross-layer feedback means the sharing of information among the layers of the protocol stack. Some of the examples of cross-layer feedback are:

1. TCP packet loss information being communicated to the application layer to enable application adaptation.
2. Delay or loss constraints of the application communicated to the link layer to enable link layer to adapt its error correction mechanism.
3. Application priorities communication to the TCP to widen its receiving window.
4. Link/MAC layer tuning the transmit power of the physical layer based on the bit error information from the physical layer.

The channel and also the topology could be dynamic in time owing to environmental factors and user mobility, respectively. The variation may well be happening at numerous time scales from milliseconds to several seconds for connectivity variations once two nodes get in and out of coverage of every other as they move. Actions at completely different layers ought to be taken reckoning on the nature of the variability so as for the network to compensate in an optimum manner. All the relevant parameters of the atmosphere that have an effect on the communication are described by the topology state variable S(t). The communication topology is depicted by Equation

$$C(t) = C(I(t), S(t)) \tag{2.1}$$

The function $C(t)$ incorporates the dependence of the link rate on the Signal-to-Interference and Noise Ratio (SINR) through the capability perform of the link. Over the virtual communication topology outlined by C(t), the traffic flows from the origin to the destination in line with the network and transport layer protocols. The network management mechanism determines the access management vector and also the traffic forwarding choices so as to accomplish bound objectives.

Table 2.1: Sensed Topology of Network Layers

APPLICATION LAYER	TOPOLOGY CONTROL ALGORITHM SEVER LOCATION NETWORK MAP
TRANSPORT LAYER	CONGESTION WINDOW TIMEOUT CLOCK PACKET LOSSES RATE
NETWORK LAYER	ROUTING AFFINITY ROUTING LIFETIME MULTIPLE ROUTING
MAC/LINK LAYER	LINK BANDWIDTH LINK QUALITY MAC PACKET DELAY
PHYSICAL LAYER	NODES' MOBILITY MOVEMENT PATTERN RADIO TRANSFORMATION RANGE SNR INFORMATION

2.2 Network Layer Interactions

The cross-layer feedback refers to the interaction among the different layers. The information exchange among the different layers is discussed in the remaining part of this section.

2.2.1 Function of Physical Layer

The information available in this layer are bit-error rate, transmit power, coding, and modulation used. The main function of this layer is transmission of raw bits with minimum bit errors using a suitable power level. It defines the physical specifications for devices and the relationship between the transmission medium and the device. **Interactions of Physical Layer**

- Application layer: The application layer is the interface layer with the network and the users. This layer can adapt to the physical layer parameters to provide Quality of Service (QoS) to the applications. The requirements of the users vary, some are delay sensitive and some are not. Hence, the required throughput, acceptable packet loss, acceptable delay variation, delays tolerance, etc can be adapted in accordance to the available transmission power and bit-error rate.
- Network Layer: The bit-error rate on an interface can be used as the guiding information for selecting the appropriate interface.
- Data Link Layer: The transmit power for packet transmission becomes optimal when the packet length and bit-error rate information is known to the link layer. The physical layer may adapt its modulation and coding depending on the battery status.

2.2.2 Function of Data Link Layer

The information available in this layer is the forward error correction schemes, frame length, handoff related events, number of retransmitted packets, and point in which the medium is available for transmission. The function of this layer is collision avoidance, fragmentation, improving link reliability through Automatic-Repeat-Request and forward error correction.

Interaction of Data Link Layer

The link throughput information can be used by the users to decide about the applications that can be run. By looking into this information, the users can expect the application performance.

- Application layer: Different frames of the application layer are treated as per requirements of the traffic pattern. Some of the frames may be delay sensitive and some may not. Based on this the frames may be categorized according to priority. Delay sensitive frames are given higher priority, so the forward error correction and automatic repeat request may be improved for high reliability requirement. This idea is based on multi-service link layer [1][3] for QoS in the internet, that adapts the link layer services based on the traffic class. The application layer is the interface with the network and the users.

- Network Layer: The bit-error rate on an interface can be used as the guiding information for selecting the appropriate interface.

- Data Link Layer: The transmit power for packet transmission becomes optimal when the packet length and bit-error rate information is known to the link layer. The physical layer may adapt its modulation and coding depending on the battery status.

2.2.3 Function of Network Layer

- Application or user layer: An application could control its sending rate based on Mobile-IP hand-off indications. A device may have multiple wireless network interfaces that can provide different levels of service. Depending on the application or user needs, the network layer could select an appropriate network interface.

- Transport: Mobile-IP hand-off delay may lead to reduced throughput due to the TCP retransmission time-out (RTO) and back-off mechanism. TCP can be informed about the event of Mobile-IP hand-off to reduce the retransmission latency. Depending on the hand-off conditions, this helps in reducing TCP retransmission latency by up to 75% and improving throughput by up to 25% [6][7].

- Data link layer: The information available in the data link layer is current FEC and number of frames. This information may be used by the network layer for routing the frames with reduced delay and retransmission.

- Physical Layer: The battery power of this layer may be used by the network for successful transmission of frames through optimum path, by reducing the power consumption and interference.

2.2.4 Function of Transport Layer

The transport layer deals with establishing end-to-end connections of the communicating nodes. This layer is the interface between the application layer and the complex hardware of the network. The application layer may communicate with using TCP or UDP protocol of the transport layer. Hence, cross-layer interactions are beneficial for protocols like TCP and UDP. Mobile adhoc networks are characterized by high bit-error rates, large delays, and packet losses. This is viewed as congestion loss in TCP that reduces the throughput. Applications may indicate their QoS requirements to the TCP whereby the receiver window sizes may be adjusted. The TCP can state the packet loss and throughput information to the application layer whereby the sending rates may be adjusted accordingly. Also the users may shutdown noncritical applications based on this input.

2.2.5 Function of Application Layer

The application layer may transmit to other layers about the applications QoS requirements like acceptable packet loss, delay tolerance, jitter, acceptable delay variations, etc. The users may deal with real time data and non-real time data. Different types of coding are applied on the multimedia data. Information about the channel condition may be adapted to perform the coding [8]. From the above discussion, the channel condition of the physical layer and data link layer are crucial for improving application performances. It becomes essential to tune the data link error control mechanisms based on the QoS requirements of the applications to improve application throughput.

2.3 Different Cross-Layer Designs

2.3.1 An Efficient Cross-Layer Architecture for Wireless Protocol Stack

The main components of this architecture are the Tuning Layers(TL) and the Optimization Sub-System(OSS) [9][10].

1. **Tuning Layer:** The Tuning Layer(TL) layer provides necessary application program interface to the Protocol Optimizer (PO) for manipulating the protocol data structures and interactions among the layers [11][12]. The TLs provide an interface to the POs for registering for events. Multiple POs can register for the same event with a TL. The TL monitors the protocol for events for which the POs have registered. On the occurrence of an event, the TL notifies the registered POs. The functionalities for manipulating protocol data structure is built in the TLs, hence no modification is required in the existing protocol stack. Due to the addition of the Tuning layer, inclusion of new cross-layer feedback algorithms with minimum intrusion becomes feasible. For the purpose of portability, each TL is subdivided into a generic tuning sub-layer and an implementation dependent access sub-layer. The generic tuning sub-layer provides an implementation independent interface to a specific protocol. For effecting a protocol optimization, a PO would invoke the API provided by the generic sub-layer of a protocol tuning layer. The generic sub-layer would in-turn invoke the API of the implementation specific access sub-layer. The MAC tuning layer provides an interface for 802.11, CDMA MAC and GPRS. Transport Tuning Layer provides an interface for various transport protocols. The implementation dependent access sub-layer provides implementation specific interface for a protocol. This layer has the knowledge about a protocol implementation in a particular operating system and is used to manipulate or monitor the values in that protocol data structure for events.

2. **OSS Layer:** This layer executes concurrently with the existing protocol stack and does not increase the stack processing overhead. The OSS is the cross-layer engines that contain many POs [13][14]. The POs take input from various layers and decides on the optimizing action to be taken to be taken to reduce packet losses and power consumption. The PO contains the algorithm for a given cross-layer optimization. On the occurrence of event at every layer, the optimization action is undertaken [15]. The POs interact with various layers for state information, events, and optimization actions.

Limitations of ECLAIR There are creation of multiple modules for the purpose of monitoring and adaptation. This requires interactions between the modules through APIs. This results in high time overhead.

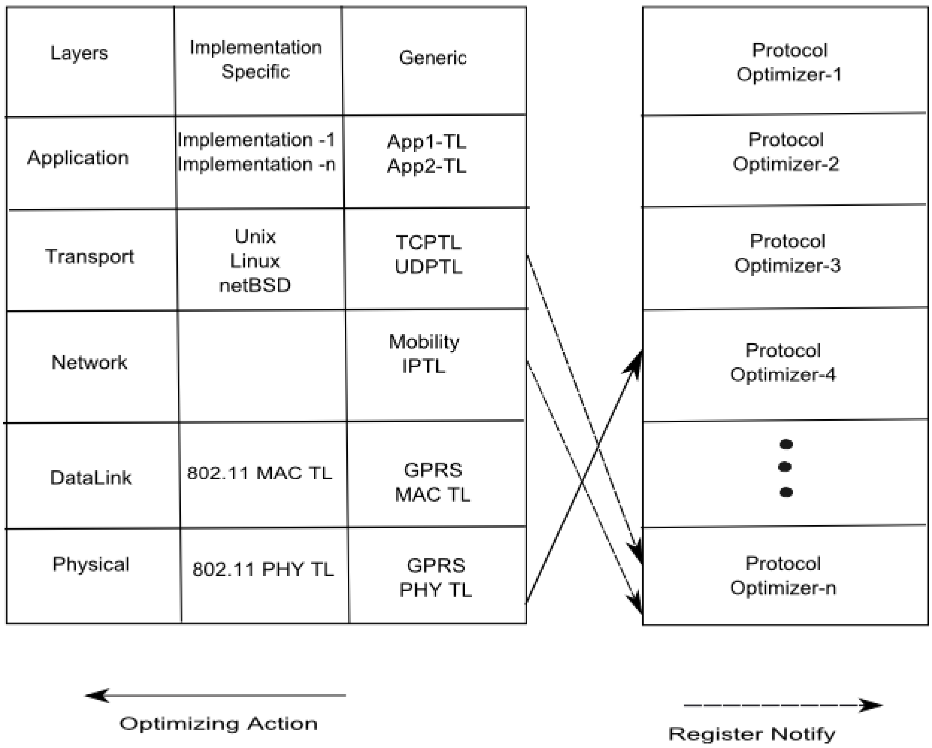

Figure 2.1: Efficient Cross-Layer Architecture

2.3.2 Direct Communication based Cross-Layer Architecture

In this cross-layer architecture, the runtime information sharing in between the layers is to allow communication between the layers. The variables at one layer become visible to the other layers at runtime. Different ways exist for the layer to communicate with one another. The protocol headers may be used to allow flow of information between the layers. Alternately, extra interlayer information could be treated as internal packets. Cross-Layer Signaling Shortcut (CLASS) is an architecture where two layers communicate directly. In this architecture only few cross-layer information exchanges are implemented [16][17]. Many issues like managing shared memory spaces between the layers are to be resolved.

Merits of the Cross-Layer Signaling Shortcuts (CLASS)

- Non-neighbouring layers of the proposed stack exchange information without processing at adjacent layers, so fast signaling information delivery to the destination is possible.

- Bidirectional signaling is possible since the CLASS messages are not related to data packets.

Limitations of Cross-Layer Signaling Shortcuts (CLASS)

The cross-layer design was designed for increasing the cross-layer feedback speed. The cross-layer feedback is built into the layer; so the layers need to be modified to adapt to each new cross-layer algorithm. Each layer is needed to generate events for informing other layers. Both of these modifications increase the processing overhead on the layers and results to reduction in the stack processing speed. This architecture demands direct communication between the layers, it introduces dependency among the interacting layers [18]. This would lead to increase in the task of maintaining the cross-layer feedback implementation.

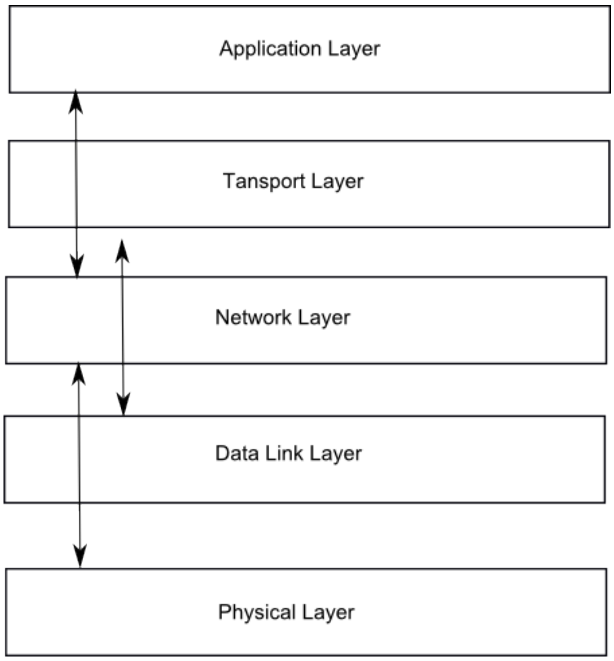

Figure 2.2: Direct Communication based Cross-Layer Architecture

2.3.3 Shared Database Cross-Layer Architecture

In this approach a new layer like, a common database is framed that can be shared by all the layers. This database is used for providing storage and retrieval of information by all the layers [19]. An optimization program can interface with the different layers at once through the shared database. New interfaces between the layers can be realized through the shared database but the main challenge of this architecture is the design of the interaction between the different layers. An example of shared database cross-layer architecture is the MobileMAN project. The MobileMAN project aims to exploit a full cross-layer design for MANETs. The architecture presents a core component; Network Status (NS) works as an information repository. The layer separation is achieved by means of standard interfaces to access the network repository. Two possible interaction models are synchronous and asynchronous. Synchronous communications take place when there is a request for private data which is on-demand in nature. A protocol layer issues a query for private data retrieval and waits for the result. Asynchronous interactions characterize the occurrence of specified conditions, to which protocols may be willing to react.

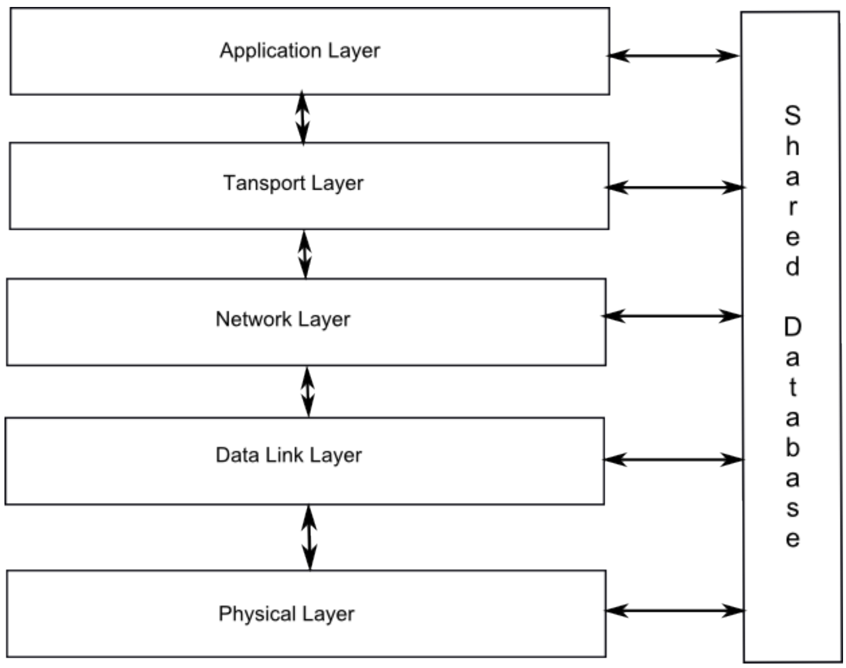

Figure 2.3: Shared Database Cross-Layer Architecture

2.3.4 MobileMAN: A Full Cross-Layer Architecture

The reference architecture of MobileMAN is a full cross-layer design but at the same time layer separation exists. Cross-layering is exploited in this architecture by information sharing among all the layers in the protocol stack [17][7]. Some of the network functions like security, QoS, energy management, etc. are cross-layer by nature. These functions need to be handled through information sharing between the protocol layers. The main feature of this approach is that, within the layered architecture, the protocols of the different layers cooperate by sharing network status information while still separating the layers. Network status (NS) is the core component in this architecture.

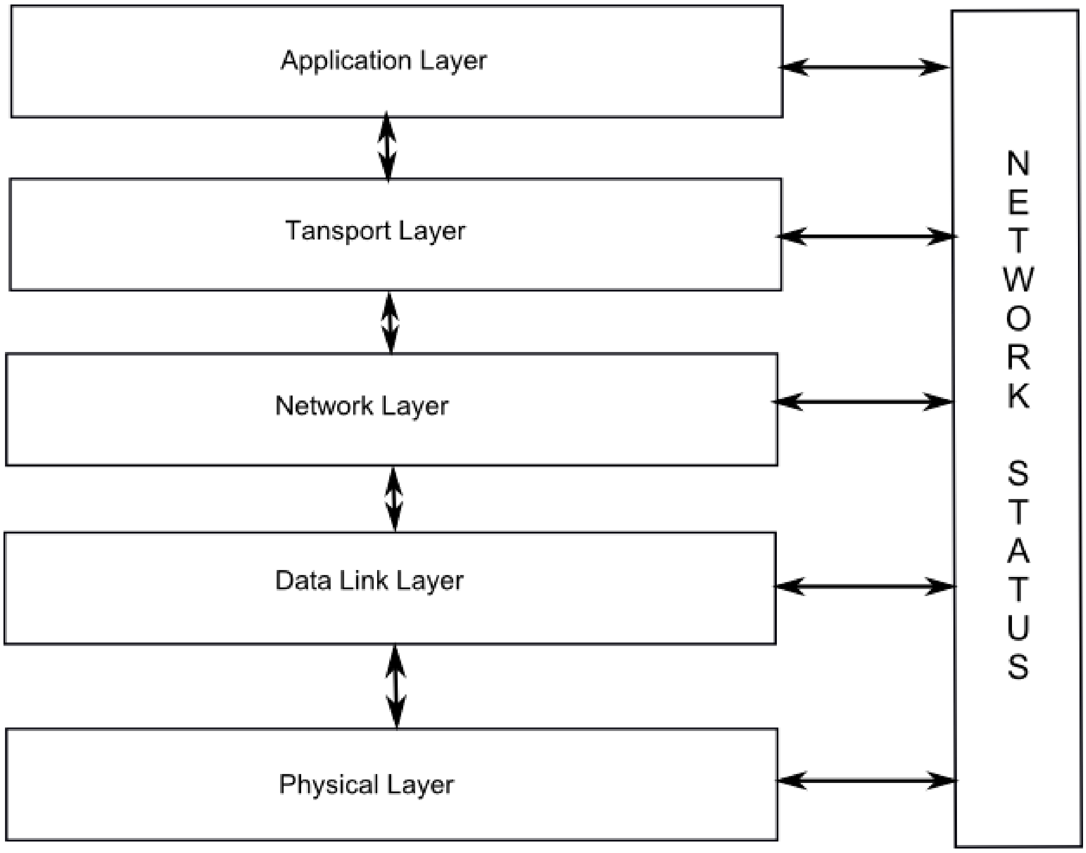

Figure 2.4: MobileMAN: A Full Cross-Layer Architecture

Network Status: It is a central repository of information, wherefrom all the layers in the protocol stack collects [16][20]. Each layer can access the NS to share its data with the other layers. By having the NS being accessible to all the layers, duplication efforts may be avoided and leads to a better system design. The layers in MobileMAN are separated by standardizing their access to the NS. The read and write operations of the layers in the protocol stack has to be defined. The interaction between the NS and the layers are placed beside the normal layer behavior, this allows optimization without compromising the expected normal functioning. Replacing a network status oriented protocol with its legacy counterpart will, therefore, let the whole stack keep working properly, although at the cost of penalizing functional optimization. There are five access methods to the repository:

- *The seize and access method* permits insert and retrieval of information from the repository.
- *The subscribe method* declares its interest to receive notification of a specific event.
- *The notify method* is used to insert data in the repository to notify event occurrences.
- *The monitor method* is used for data gathering and monitoring of the repository.

Advantages of MobileMAN Architecture

- Full compatibility with the existing strict-layering as there is no modification to the core functions of the protocol stack.
- Maintains modular architecture.
- This architecture provides robust upgrade environments, which permit the addition or removal of protocols belonging to different layers from the stack without modifying the operations at the other layers.
- Improved local and global adaptation.

Limitations of MobileMAN Architecture:

- The creation of the network status component requires substantial modifications in the protocol stack.
- It makes difficulty to add new cross-layer optimization to the stack.
- Dependency occurs between the network status component and the protocol. So, modifications in the NS component require all the protocol layers to be modified. This increases overhead.
- There is increased stack processing overhead as the protocol executes additional code for monitoring the network status and determining appropriate action.

2.3.5 ICMP Message Passing based Cross-Layer Architecture

Internet Control Message Protocol (ICMP) messages are the standardized way of signaling event information from one layer to other layer. It involves operation with protocol headers: IP Header and ICMP. Different methods of signaling using the ICMP messages are:

Packet Headers: Signaling Pipe The network layer information may be added as additional header in the IPv6 [17]. The interlayer signaling pipe stores the cross-layer information in the wireless extension header (WEH). This method makes use of IP data packets as in-band message carriers with no need to use a dedicated internal message protocol. IP packet can be processed from layer to layer; it is not easy for higher layers to access the IP level header. Protocol adaptation is built into the protocol itself. Hence, the time overhead is low. Interlayer signaling pipe architectures require the modification of one or more protocol layers to gather environment information and to transmit it to other layers via the protocol stack. Environment information is detected at appropriate protocol layers and assembled into cross-layer packets, which are injected into the protocol stack in the direction of the recipient layer. The recipient layer recognizes the cross-layer packet, reads the environment information contained therein, and utilizes the information to influence its own decision-making. The signaling pipe is bottom to top approach. Although the ISP is implemented within the mobile host, the network nodes and the corresponding host can read the information if they are WEH-aware.

Limitations of Signaling Pipe: The protocol stack needs to be modified, to introduce adaptations and feedback. This results in poor maintainability and high data path delay.

1. **ICMP Messages:** The ICMP messages are encapsulated in the IP packet and passed from layer to layer. Since a message could be generated from any layer and then terminated at a higher layer, cross-layer signaling is carried out through these selected holes, rather than the pipe. The ICMP messages encapsulated by IP packets have to pass by the network layer even if the signaling is only desired between the link layer and the application layer. The cross-layer communication is carried out through selected holes and not through general pipe. So, this method is flexible and efficient.

2. **Local Profiles:** The cross-layer information is abstracted from the related layers and stored in a separate profile inside the mobile host. The other layers that are interested can select profiles to fetch desired information. This method is flexible since profile formats can be tailored to specific layers that can access the information directly.

3. **Network Service:** A third party maintains a Wireless Channel Information (WCI) server. The channel and link information from the physical and data link layers is gathered, abstracted, and managed in the WCI. As a network service, it is complementary to the former schemes within an MH although some overheads in the air are incurred and interfaces have to be defined among the MH, the WCI server and application servers.

Limitations of ICMP Message Passing based Cross-Layer Architecture

- The message passing is only in the upward direction. The upper layers cannot communicate with the lower layers. Therefore, it does not enable any-to-any layer feedback in general.
- The architecture does not provide mechanism for defining adaptation for layers below the transport layers. It requires modifications to the protocol stack to introduce application and transport action tables and new ICMP handler.
- The protocol layers needs modification to introduce new APIs in the protocol stack to support adaptation. A new variable has to be introduced to allow modifications in the protocol behaviour. These modifications lead to difficulty to ensure correctness and increased effort for stack code maintenance.
- The cross-layer feedback overhead is higher since the messages are encapsulated in ICMP messages. The adaptations of the transport layer are based on the actions stated by the application. Therefore, the transport protocol is adapted for each application separately and there is no mechanism to have a common adaptation for all the transport layer sessions.

2.3.6 Layer Manager based Cross-Layer Architecture

The cross-layer manager is exposed to the events and state variables of the protocol layers [21]. The management algorithms to perform the cross-layer information processing use these events. The cross-layer manager uses the state variables to query and set the protocol internal state. To extract the benefits of cross-layer design, the concept of coordination plane was introduced [10]. A coordination plane is a cross-section view of the protocol stack on which interlayer coordination algorithms are applied and it solves a set of problems of the same kind. Four coordination planes were been identified:

- Wireless link adaptation: includes cross issues, bit error rate and error rate adaptability.
- Mobility: includes the problems created by mobility scenarios.
- Security: includes elimination of multilayer encryption.
- QoS: includes distribution of QoS requirements.

Limitations of Layer Manager based Cross-Layer Architecture

- The layers are to generate events to feed to the cross-layer manager. This leads to slow down of layer execution.
- Further, the cross-layer manager is dependent on the protocol implementation since it reads and updates state variable information of a protocol.

2.4 Sources of Power Waste in Ad-hoc Network

The major sources of power waste in mobile computing devices embody radio communication and data processing. Data processing involves the usage of central processing unit, memory, hard drive, etc. Its energy consumption is comparatively negligible compared therewith of the radios. The energy expenditure in radio communication includes the power consumed by transmission and receiving devices of all nodes on the path from source to destination, in conjunction with their neighbours that may hear the transmission. Actually, there is an exchange on energy consumption between data processing and radio communication [21]. Information compression techniques are introduced into scale back packet length, and thus, accomplish energy saving in radio communication, however, the value of computation is magnified [22].

In mobile ad-hoc networks, communication related energy consumption includes the power consumed by the radios at the sender, receiver, and intermediate nodes within the route from the supply to the destination. Actually, at any time a mobile node in MANET should be in one in all the subsequent four modes: transmit, receive, idle listening, and sleep. Once a node is in transmit or receive mode, it is sending or receiving a packet. Idle listening mode means that the node is neither sending nor receiving a packet, however, is doing channel watching. This mode consumes power as a result of the node must hear the wireless medium ceaselessly so as to observe the arrival of the packet that it ought to receive, so the nodes switches to receive mode [23].

Further, the energy expenditure for the radio interface to transit from one mode to a different is not negligible as a result the transition time cannot be infinitesimally short. For instance, the transition between transmit and receive modes generally takes 6 to 30 ps, whereas the transition from sleep to transmit or receive typically takes even longer (250 ps) [19]. Mode transitions have vital impact on energy consumption of wireless nodes.

Significant energy expenditure is incurred owing to packet retransmission, node overhearing and protocol overhead caused owing to collisions [24]. Retransmission of the corrupted packets will increase energy consumption. Owing to the shortage of a centralized authority in mobile ad-hoc networks, transmissions of packets from distinct mobile terminals are additional susceptible to overlap, leading to additional serious packet collisions and energy loss. Overhearing means that a node picks up packets that are destined for alternative nodes. Wireless nodes can consume power unnecessarily owing to overhearing transmissions of their neighbouring nodes. Protocol overhead is generated by packets dedicated for network management and header bits of knowledge packets. It ought to be reduced the maximum amount as potential as a result of transmitting data packet headers or control packets additionally consumes energy, which ends up within the transmission of fewer amounts of helpful data packets.

2.5 Multi-Layer Power Conservation

Power conservation in an ad-hoc network is that the procedure of determining the transmit power of every communication terminal such a style objective like network lifespan and throughput may be satisfied. There are two major reasons for transmit power control. First, transmission at a high power could increase the interference to the neighbouring nodes and so degrade network throughput. Power saving mechanisms are shown to be able to decrease multiuser interference, and therefore, increase spatial channel apply and also the variety of concurrent single hop transmissions. One direct advantage of this increase is that the enlarged overall traffic carrying capability of the network [25]. Second, energy efficient schemes will impact battery life, consequently prolonging the lifespan of the network. Current power management mechanisms embody low power wireless access protocols, power-aware routing for ad-hoc and sensor networks [26][27] and node level energy efficient information processing [28].

Power conservation needs cross-layer style and also the want for power potency should be balanced against the lifespan of every individual node and also the overall lifetime of the network. Power management incorporates an important impact on protocols higher than the physical layer. The amount of transmitter power defines the neighbourhood nodes and also the context within which access, routing, and alternative higher-layer protocols operate. Therefore, power management plays a key role within the development of economical cross-layer networking protocols.

The power conservation procedures within the completely different network layers provide a transparent indication that to affect power scarceness every layer has to be compelled to participate directly or indirectly through layer interaction. This section discusses the cross-layer design for borderline power conservation in Figure 2.2.

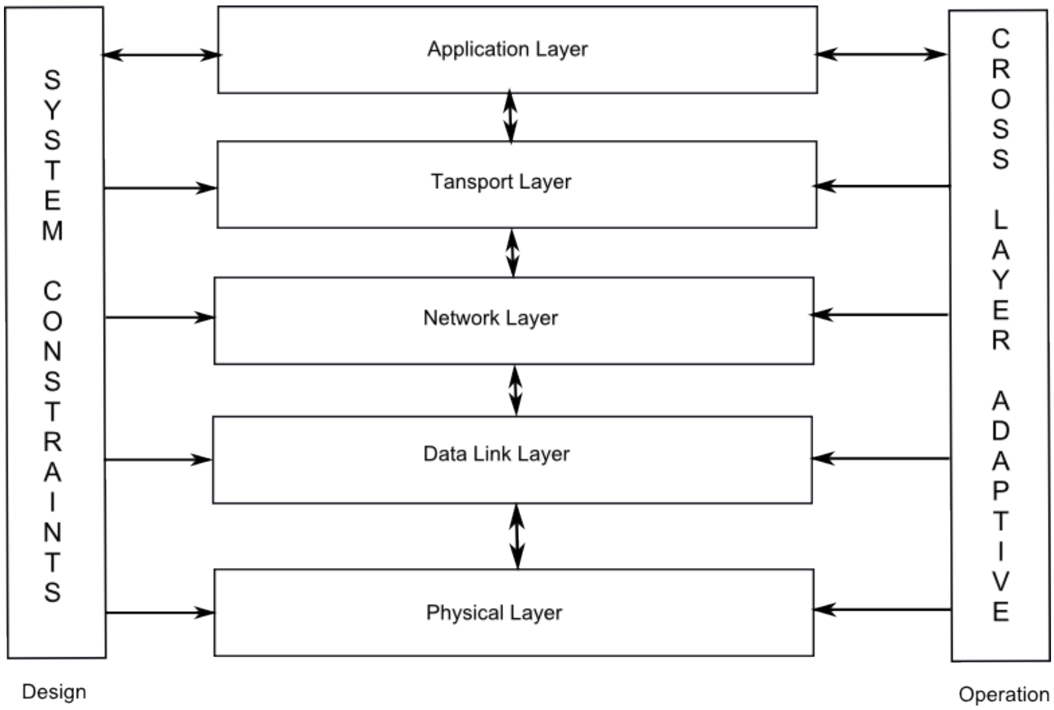

Figure 2.5: Cross-Layer Design

2.5.1 Power Conservation at the Link Layer

The design of link layer in ad-hoc networks aims to attain data rates near the elemental capacity limits of the channel by overcoming channel impairments with very little energy.

Gallager et al. [29] in their work discovered that reliable communication is outlined beneath a finite range energy constraint in terms of the capability per unit energy. It indicates that ad-hoc networks with finite energy nodes solely have a finite range of bits that a given node will transmit before exhausting its energy. Allocating those bits to the various needs of the network like information transmission, exchange of routing info, forwarding bits for different nodes, channel estimation are a stimulating and difficult improvement downside that clearly need cross-layer style.

Gamal et al. [30] states that channel coding will considerably reduce the power needed to achieve a given bit error rate and so is a typical feature in energy forced link layer style. The study is especially focused on the Turbo coding and space-time coding.

Spyopoulos et al. [21] in their study stated that exploitation of multiple antennas at the transmitter and receiver plays another powerful role in reducing the desired transmit power. They illustrated that 45% improvement in energy value for routing is achieved employing a directional multiple antennas.

2.5.2 Power Conservation at the MAC Layer

The design of MAC layer in ad-hoc networks aims to avoid unnecessary collisions attributable to hidden and exposed stations since retransmission incurs power consumption. IEEE 802.11 WLAN avoids collision mistreatment by four-way handshake before transmission and relies for single-hop routing. Another technique to avoid hidden and exposed terminals is busy tone transmission owing to this methodology fits well only the centralized controller may be detected by all users.

Wu et al. [31] in their work investigated hybrid techniques mistreatment handshakes, busy tone transmission, and power control. The next approach to save lots of power is to own the receiver in standby than having it supercharged in the least times within the wireless network. A schedule may be broadcasted portraying the transmission times for every mobile device. In a very single-transceiver system, switch type transmit to receive mode is needed to support each transmission and down link communications. By allocating contiguous slots for transmission and reception, power consumption as a result of mode switch may be reduced. For channel reservation, request of multiple slots with one reservation packet might conserve power. From another perspective, wide power savings may be obtained by showing intelligence turning of radios once they cannot transmit or receive packets.

Delay is another parameter that must be controlled in wireless ad-hoc networks.

Kandukuri et al. [32] in their work illustrated power control strategy for multiple accesses that takes account of delay. This strategy optimizes the transmit power relative to each channel conditions, and therefore, the delay constraint via dynamic programming. The optimum strategy exhibits three modes: terribly low-power transmission once the channel is poor and tolerable delay is massive, higher power once the channel and delay is average, and extremely high-energy transmission once the delay constraint is tight. This strategy exhibits important power savings over constant power transmission whereas meeting the delay constraints of the traffic.

2.5.3 Power Conservation at the Network Layer

The design of network layer in ad-hoc networks aims to support efficient routing as every node has got to act as a router and packet forwarder as there is not any base station. Hence, the computation and communication load of packet process, transmission, reception, etc. will be quite high. Power control strategy wants connectivity information that is provided by the routing layer. These mutual dependants motivate the requirement for a joint resolution for power control and routing.

Singh et al. [33] illustrated the usage of power-aware metrics to determine routes in wireless ad-hoc networks. It absolutely was argued that routing protocols that derive routes based on minimizing hop count or delay can end in some nodes depleting their energy reserves faster, inflicting them to be high-powered down at an earlier stage. In addition, routing packets through gently loaded nodes is taken into account energy preserving since there is less probability of competition.

A number of the metrics proposed for power-aware routing are:

1. Minimize energy consumed per packet,
2. Maximize time to network partition,
3. Minimize variance in node power levels,

4. Minimize cost per packet,

5. Minimize node cost.

Other approaches to conserve energy is to transmit packets with compact header, using periodic route updates within the routing table and mobile agent based mostly topology discovery techniques is also used.

Pursley et al. [15] in their study states that routing protocol below energy constraints should somehow balance delay constraints, battery period of time and adaptation secret writing. Thus cross-layer style based routing protocol is important to reduce the energy price of routes. Narayanaswamy et al. [34] planned a protocol named COMPOW that satisfy the three objectives of increasing the traffic carrying capability of the complete network, extending battery life through providing low power routes and reducing the competition at the MAC layer. This protocol has the plug and play feature that proactively maintains a routing table.

2.5.4 Power Conservation at the Transport Layer

The design of transport layer in ad-hoc networks aims for reliable transmission of messages between the sender and receiver. Wireless ad-hoc networks suffer from frequent topology changes owing to high quality that result into delays and packet losses. The packet losses are also understood as congestion and thereby invoking congestion management that cause extra retransmissions and power consumption. To beat this drawback, a feedback theme is planned in order that supply will distinguish between route failure and network congestion.

Chandran et al. [35] planned power efficient error control schemes. TCP employs Automatic Repeat Request (AREQ) to observe error and request for retransmission, however, energy is consumed for recurrent retransmission and should be avoided the maximum amount as attainable.

Study by Lee et al. [36] manifested that the performance of multiple TCP or UDP connections over numerous ad-hoc routing protocol and link state is sort of totally different in fairness constant and output. Therefore, the power management strategy in transport layer should coordinate to network layer and different lower layers.

Minare et al. [37] explored the topology discovery theme by victimization agents, wherever the nodes in these systems are dummy and data exchange is unidirectional. The navigation ways do not guarantee balanced distribution of recent topology data among all nodes. This limitation will be solved by creating the nodes discover neighbours through exchanging BEACON packet with the agents. Also, link stability will be outlined and data aging based mostly prognostic rule will be used to run on every node to predict this configuration. It is ascertained that joint mobile agents and periodic beacon based mostly topology discovery rule is possible. Topology management ways play a very important role since it should be dense enough to be sturdy and thin enough to alter abstraction utilize. Every node regulates its transmit power to make sure that the quantity of a neighbour node is nice enough through BEACON packet exchange.

2.6 Related Power Saving Protocols

2.6.1 Scheduling based Protocols

1. **Access CDMA (CA-CDMA)** Muqattash et al. [38] proposed a unique Controlled Access CDMA (CA-CDMA) protocol that solves some of the drawbacks for CDMA ad-hoc networks. In CA-CDMA, all nodes use a typical spreading code within the control channel to contend for the channel resource with a modified RTS/CTS mechanism. Information packets are transmitted within the data channel encrypted with completely different terminal specific codes. By using two non-overlapping frequency bands, it is simple to urge a code within the management channel orthogonality with each code within the information channel. Hence, nodes will transmit and receive at the same time over the management and information channels notwithstanding what quantity the signal power is. This makes it possible to allow interfering nodes to transmit at the same time. CA-CDMA adjusts the sending power per channel-gain information so concurrent transmissions are possible.

   Figure 2.6 depicts the code assignment scheme employed in CA-CDMA [38]. The results show that CA-CDMA will improve the network throughput by 280 percent and save 50 percent energy consumption compared with IEEE 802.11. Energy savings are achieved in CA-CDMA by using orthogonal codes to realize the goal of channel employ. Based on the orthogonality between the control channel and the information channel, coincidental transmissions are created possible such that the throughput is improved with the same or less energy consumption.

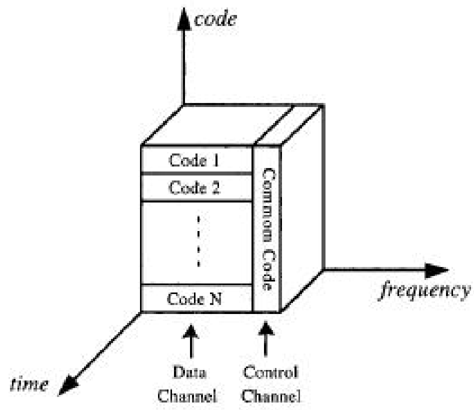

Figure 2.6: Code-Assignment-CDMA

2. **CDMA/TDMA**

   In [39], a MAC protocol based on CDMA/TDMA for energy-limited single-hop circumstantial networks is projected. The main idea is predicated on the observation that radio module consumes additional power in transmission mode than in reception mode, and the least power in sleep/idle mode. The motivation is to inform each terminal through MAC layer control once to get up from sleep mode and once to sleep from transmission/reception mode so as to save battery power. This motivation is similar thereto of the power management mechanism to be mentioned within the following section. During this protocol, such a design objective is achieved by a scheduling and reservation technique based on CDMA/TDMA.

   There are two completely different kinds of mobile terminals defined during this MAC protocol: a pseudo base stations (PBS) and traditional mobile nodes. The PBS is introduced to emulate a base station (BS) in infrastructure networks. It is to blame for the centralized management of collecting requests from mobile terminals and allocating CDMA codes and TDMA slots. PBS plays a vital role in power conservation. First, the PBS selection/reelection is predicated on battery power. Solely high power node will function as the PBS. Second, the planning is predicated on the power level of every traditional terminal. Nodes with lower power have higher priority in allocating radio resources. This will effectively cut back the possibility of early termination of low power nodes. By this way, the battery energy of high power terminals is shared at intervals all nodes and the network lifespan is extended. Simulation results show that this protocol will effectively shield mobile terminals from collision and retransmission once traffic is significant. Low power terminals work higher than high power nodes, especially in energy efficiency. However, with the centralized control by the PBS, this protocol will solely support single-hop wireless ad-hoc networks.

2.6.2 Power Control based Protocols

1. **Power Control MAC:** A Power control MAC (PCM) protocol is proposed in [40] to allow per packet choice of transmits power. In PCM, RTS/CTS packets are transmitted with most power level however data packets are transmitted with lower power level. To avoid a potential collision caused by the reduced carrier sensing zone, throughout the data packet transmission, PCM periodically will increase the transmission power to most and ACK packets square measure transmitted with the minimum needed power to achieve the supply node. This way, retransmission is avoided as much as double and correspondingly, the goal of energy savings is achieved. Results show that PCM are able to do a throughput such as the IEEE 802.11 however, with less energy consumption. Yet, PCM requires a frequent increase and reduces in transmission power levels, this makes the implementation complicated.

2. **Power Controlled Multiple Access:** Power Controlled Multiple Access (PCM) Protocol [41] proposes a versatile collision suppression model that permits variable transmit power levels on a per packet basis. It uses RPTS/APTS handshaking to work out the bottom transmission power needed for self-made packet reception. This scheme introduces a busy tone channel, to implement the noise tolerance advertisement. Throughout data transmission periods, each active receiver can periodically send a busy tone to advertise the maximum further noise power it will tolerate. Any potential transmitter should sense the channel first for busy tones to work out the boundary of its transmitting power for a minimum fundamental quantity (determined by the frequency with which the busy tones square measure transmitted). Actually, PCMA uses the signal strength of a received busy tone messages to sure the transmission power of neighbouring nodes. This way, power control mechanism is realized and spatial apply is achieved. PCMA works effectively in energy conservation since it permits additional simultaneous knowledge transmission compared with IEEE 802.11 normal by adapting the transmission ranges to be the minimum price needed for self-made reception on the receiver side. The power controlled

transmission in PCMA helps to increase channel potency at constant time preserving the collision shunning property of multiple access protocols.

3. **Dynamic Channel Assignment with Power Control:** A Power Control MAC (PCM) protocol is planned in [41][42] to allow per packet selection of transmits power. In PCM, RTS/CTS packets are transmitted with maximum power level but data packets are transmitted with lower power level. To avoid a potential collision caused by the reduced carrier sensing zone, throughout the information packet transmission PCM periodically will increase the transmission power to maximum and ACK packets are transmitted with the minimum required power to succeed in the supply node. This way, retransmission is avoided as much as possible and correspondingly, the goal of energy savings is achieved. Results show that PCM are able to do a throughput similar to the IEEE 802.11 but with less energy consumption. However, PCM requires a frequent increase and reduce in transmission power levels, this makes the implementation complex.

4. **Dynamic Channel Assignment with Power control (DCA-PC)** A Dynamic Channel Assignment with Power management (DCA-PC) is proposed in [42]. This power control protocol uses one control channel to transmit all the control packets (RTS, CTS, DATA, ACK, etc.) and can assign multiple data channels on demand. The nodes use an RTS/CTS dialogue to determine that channel to grab and that power level to use for information transmission. An RES message is employed to reserve the information channel there once data packets and ACKs are transmitted on the reserved data channel victimization with the assigned power level. The control packets are transmitted with a maximal power level so as to warn the neighbouring nodes of the communication. The information packets are transmitted with correct power levels for channel use. DCA-PC is that the first protocol to appreciate the mechanisms of power data and multi-channel medium access along with MAC protocols of MANETs. By exploitation of multiple channels, it is easier to extend the throughput, reduce normalized propagation delay per channel, and support quality of service.

2.6.3 Multi-Channel based Protocols

1. **Power Controlled Dual Channel (PCDC)**

   The Power Controlled Dual Channel (PCDC) Medium Access Protocol [43] uses two channels: one control channel and one data channel. It utilizes the inter-layer dependency between the MAC and network layers to produce an efficient and comprehensive power management theme. The concept is based on the observation that the transmission power has direct impact not only on the floor reserved for consecutive transmission but also on the selection of consecutive hop node. Hence, the interaction between the MAC and network layers can help for a good power management theme to pick out the bottom possible power level whereas maintaining the network connectivity and correct MAC function. It uses distributed rule to calculate a minimal connectivity set (CS) for each node. By dominant the transmission power of a route request (RREQ) packet, PCDC broadcasts the RREQ packets to the connectivity set only, thus the MAC can effectively control the set of candidates for next-hop nodes. Since RREQ packets are only transmitted to the nodes in the connectivity set, it is simple to regulate the potential competition. Hence, the process to seek out the destination in PCDC has low overhead, less competition, and fewer power consumption. However, the adaptive computing of the connectivity set may impose lots of computing workload for each node.

2. **Common Power (COMPOW)**

The COMPOW [44] proposes to use a common power level to confirm bidirectional links. Each COMPOW node runs several instances of a proactive ad-hoc routing protocol (eg., DSDV), at a distinct transmit power level. A set of routing tables are maintained that contains the corresponding connectivity information. The optimum power is outlined to be the minimum power whose routing table has a similar variety of entries as that of the routing table at maximum power level.

COMPOW is meant to maximize the traffic capability of the network, provide power aware routes and reduce the contention at the MAC layer. Thus, energy consumption is reduced at a similar time that network capability is redoubled. However, COMPOW completely relies on routing layer agents to converge to a common power level. This sometimes incurs important overhead, especially for perpetually moving mobile nodes. Normal clustering ad-hoc networks, such a common power level is also tougher or perhaps unworkable to attain, thanks to the stratified architecture. Clustering by power control is employed for non-homogeneous ad-hoc networks [45]. Clustering is employed for non-homogeneous situations. It classifies nodes hierarchically into clusters, dominated by ”cluster-heads” and connected by ”gateways”. Cluster-heads are used as base stations to emulate power management as in an infrastructure network. The main plan of such a kind of power control is based on the observation of the very high energy value of an idle interface.

Therefore, by emulating the infrastructure operative mode through clustering, energy consumption is often reduced by lease the cluster-heads control the intra-cluster knowledge transmission. Completely different power levels are used in the intra-cluster and inter-cluster communication with a high power level among the cluster-heads and a low common power level among most of the intra-cluster communication. On the other hand, clustering also can help in reducing the route discovery overhead. They both help reduce energy consumption.

3. **Power-aware Multi-access Protocol with signaling:**

   The Power-aware Multi-access Protocol with Signaling (PAMAS) [46][47] is planned to conserve battery power by powering off nodes that do not seem to be transmitting or receiving. This can be a mixture of the original MACA protocol [48] and the use of a separate signal channel the "busy tone" channel [49]. By using busy tone, the terminals are enabled to work out once and how long they must power off the radio.

   The determination should obey the following rules:

   (a) If a host has no packets to transmit, then it should power the radio off if one in every of its neighbouring nodes begins transmitting.

   (b) If at least one neighbouring node is transmitting and another is receiving, the host should also power itself off as a result of it cannot transmit or receive packets even if its transmit queue is nonempty.

   In the proposed protocol, each host makes the choice whether or not to power off the radio severally. A number knows whether or not a neighboring node is transmitting as it can hear the transmission over the channel. Similarly, a node with a nonempty transmit queue knows if one of its neighbours is receiving as a result of the receivers should transmit a busy tone after they begin to receive packets and in response to the RTS transmissions. Thus, a number can simply decide once to modify to the sleep mode. Futher, PAMAS also gives several factors to work out the length of time for which nodes are often in sleep mode, empty transmit queue, and control packet.

4. **S-MAC:** An energy-efficient MAC protocol for wireless sensor networks, called S-MAC is proposed in [50]. Completely different from PAMAS, S-MAC uses the scheme of periodic listen and sleep to scale back the energy consumption by avoiding idle listening. However, this requires synchronization among neighbouring hosts and the latency is multiplied since a sender must await the receiver to come to life before transmission. However, S-MAC uses synchronization to make virtual clusters of nodes on constant sleep

schedule. This technique coordinates nodes to attenuate additional latency. Another difference from PAMAS is that S-MAC uses the in-channel signaling to put the nodes in sleep mode when its neighbouring node is in transmission. The in-channel sign helps scale back the over hearing problem and avoids the employment of additional channel resource.

5. **Pico Node's Multi-Channel**

   A low power distributed MAC is proposed in UC Berkeley's Pico Node project [51]. A power saving mode based on wakening radio without synchronization is used during this MAC protocol. With a separate come to life radio, the traditional data radio can be powered down when it is in idle listening state. Multiple channels and CSMA/CA are combined within the MAC for efficient energy usage. The multi-channel unfold spectrum helps scale back collisions and retransmissions. The exploit of random access results in the turning away of synchronization since it does not require any topology information. Thus, there is no overhead in exchanging schedules and reservation information.

   All these measures help in energy consumption reduction. Simulation results show the proposed protocol can scale back the ability consumption by 10-100 times compared with existing MAC protocols with ancient radio. As outlined by the MAC protocol, each terminal within the network is either in ”mobile mode”, or ”static mode”. Mobile nodes periodically broadcast a beacon through the wake-up channel to keep the neighbouring nodes awake, therefore, maintaining a dynamic active zone among two hops. Channel assignment is conducted as the problem of two hop colouring in graph theory. Static hosts within the active zone remain awake. They are going back to sleep mode once more when no beacon has been received for a predefined amount. Underneath two instances a node can be woken up: it has packets to transmit, or it will receive packets from a neighbour. A node can be woken up by itself, or by a beacon from a neighbouring node through the wake-up radio channel.

6. **Power Management using Multi-Sleep States**

   A distributed power management policy is introduced in [52] for ad-hoc networks. This policy aims to maximize energy conservation in powered devices whereas satisfying the specified traffic quality of service. In this paper, totally different L states are used: the primary $L-1$ state are sleep states, whereas the $L-th$ state corresponds to the active state within which nodes will transmit or receive packets. Each sleep state is characterized by a certain amount of power consumption and a delay overhead. The deeper the sleep state, the less the ability for consumption and also the longer the time to wake up.

According to the specified QoS and its own battery standing, each terminal should choose an acceptable sleep state when it has been idle for an explicit time period up to or bigger than the corresponding timeout value. The sleeping node switches back to the active state when it receives the signal from the Remote Activated Switch (RAS). Simulation is conducted to review the ability gain in a very straightforward network scenario that assumes L = 4. Results show that power gain as high as 24% may be obtained even at high traffic load. However, this gain is achieved at the expense of a limited further delay. Compared with periodic sleep mechanisms, the most important advantage of this power management policy is the remote communication theme. By mistreatment the radio frequency (RF) tags technology, this policy avoids the requirements of clock synchronization. In this approach, nodes are woken up only when necessary, rather than switched back to a vigorous state periodically to examine for potential traffic.

7. **Dynamic Channel Assignment (DCA)**

Wu et al. [53] propose a Dynamic Channel Assignment (DCA) protocol that assigns channels dynamically in associate degree on-demand style. This protocol exploits one control channel to resolve contentions on data channels and assign data channels to mobile hosts. Multiple data channels are offered for data transmission. During this protocol, all data channels are equivalent with a similar information measure. Each host has two half-duplex transceivers, so it will listen on the control channel and its data channel simultaneously.

For a mobile node A to speak with B, A sends a RTS to B carrying its free channel list (FCL). Such list includes all information about the data channel condition around A. Then B matches this FCL with its channel usage list (CUL) to pick out a data channel for subsequent communication and replies A with CTS. Once receiving B's CTS, A sends a RES (reservation) packet to inhibit its neighbourhood from victimization of a similar channel. Similarly, the CTS inhibits B's neighbours from victimization of that channel. These entire messages are transmitted on the control channel. Once this handshaking protocol is finished, data packets and their ACK messages are changed on the selected data channel. Channels are allotted on demand during this protocol. There is no need for clock synchronization. So channels are used with little control message overhead. Results show that DCA suffers less collision and corruption compared with an easy 802.11, like multi-channel protocol. The introduction of the control channel and multi-data channel helps to cut back unwanted power consumption.

8. **Dual Busy Tone Multiple Access protocol (DBTMA)**

In DBTMA[54][55], two busy tones, specifically transmit busy tone and receive busy tone, are placed on the offered spectrum at different frequencies with enough separation.

The receive busy tone provides two functions:

- Acknowledge the sender that the channel has been with success non-heritable.
- Notify its neighbouring nodes of the subsequent transmission and provides continuous protection for the ongoing traffic.

The transmit busy tone is employed to safeguard the RTS packets. With these two busy tones, exposed terminals will establish their own transmission. Instead, the acknowledgment of the sure-fire channel request are sent by means of the receive busy tone. Moreover, the hidden terminals will reply to the RTS requests by simply fitting its receive busy tone. Power control technique is additionally exploited in DBTMA. Simulation results show that DBTMA protocol is superior to RTS/CTS-based protocols, like MACA [48], MACAW [56], and FAMA-NCS protocols, which work on one channel. DBTMA achieves the performance gain as high as 140% over MACA and FAMA-NCS, 20% over RI-BTMA. It additionally reduces the amount of potential collisions and corruptions. However, this theme needs hardware support. Additional busy tone transmitters and sensing circuits need to be incorporated into each wireless terminal.

9. **Directional MAC**

In [57], directional antennas are applied to the IEEE 802.11a MAC protocol. RTS, data and ACK packets area unit sent directionally and a higher performance is achieved than current MAC protocols since it allows synchronous transmissions that do not seem to be allowed by the present MAC protocols.

Directional MAC protocol works with the following assumptions: All the terminals during a region share a wireless channel and communicate on the shared channel. Each node is provided with multiple directional antennas. Transmissions from two completely different nodes can interfere at some node X, though at X, completely different directional antennas used to accustom receive the two transmissions. Synchronous transmissions to completely different directions do not seem to be allowed at any node. Beneath these assumptions, several doable cases area unit thought-about and 2 completely different schemes are planned in [57]. Directional MAC scheme-1 for using solely directional RTS (DRTS) packets and directional MAC scheme-2 for using each DRTS and omni-directional RTS (ORTS) packets.

The use of RTS and CTS packets allows the corresponding recipients to determine the direction of the transmitters. These directions area unit then used for directional transmission and reception of the info packets. Additionally mentioned associate degree optimization victimization directional Wait-to-Send (DWTS) packets to forestall reserve retransmissions of RTS packets. However, it relies on associate degree accurate chase and locating technology, such as GPS or periodic location beaconing, which may be impossible in some cases.

10. **Directional Antenna based MAC Protocol with Power Control (DMAPC)**

In [58], a new transmitting aerial primarily based MAC protocol with power control (DMACP) is planned which uses directional antennas at the side of power control technique. DMAPC focuses on the difference of IEEE 802.11 thus on find practical solutions for:
(a) Finding the directions of transmission/reception at mobile nodes.
(b) Designing applicable transmission and reception methods for the MAC control packets to minimize interference amongst distinct pairs of human activity hosts.
(c) Implementing the power control strategy for data transmission to scale back power consumption.
In addition, [58] discusses a way to take advantage of directional antennas and gift some practical schemes for implementing directional RTS and CTS transmissions.

Results show that the use of directional antennas offers many benefits, such as important power savings, network output improvement, and much less interference. However, all these benefits do not come back for free. Completely different from the omni-directional antennas primarily based scheme, the antennas of transmitters/receivers need to be geared toward each other before the communication starts. The implementation is complex, and therefore the hidden terminals, hearing impairment problems can also exist [28].

11. **MAC Protocol using Directional Antennas**

In [59] the protocol proposed avoids the requirements for hardware support by exchanging omni-directional RTS/CTS frames. The direction of a transmitting host is decided through measurement the signal strength, and therefore, the need for GPS receivers is eliminated. The scheme is based on the IEEE 802.11 protocol, except for some modifications for adapting the use of directional transmission. The key modification is a mechanism for the pair of human activity nodes to acknowledge the direction of every different through the RTS/CTS exchange. No location data is needed, which helps cut back the interference.

According to [59], the radio transceiver in each mobile node is assumed to be equipped with M directional antennas. Each of the antennas has a conical pattern, spanning associate degree angle of 2n/M radians. The M antennas in each host area unit fixed with nonoverlapping beam directions, thus on put together span the complete plane. Simulation experiments indicate that by victimization the planned protocol with four directional antennas per node, the average output in the network are often improved up to a pair of three times over those obtained by using CSMA/CA schemes based on RTS/CTS exchange with traditional omni-directional antennas. However, since the planned protocol uses omni-directional RTS/CTS exchange, it loses the advantages of reduced transmission area.

12. **Distributed Power Control**

    A distributed power control (DPC) protocol is proposed for ad-hoc network stations with good antennas in [60]. In the planned protocol, the receivers gather native interference data and send it back to the transmitters. Then, the transmitter will use this feedback to estimate the power reduction factors for every activated link. The feedback data consists of the corresponding minimum SINR (Signal-to-Interference and Noise Ratio) during RTS, CTS, data and ACK transmission. Here, data, and ACK transmissions area unit in (beam formed) array-mode since smart antennas are used at each ends of the link.

    In DPC protocol, the interference data is collected during each omni-directional RTS/CTS transmission, and therefore, the beam formed DATA/ACK transmission. RTS /CTS packets are continually transmitted with full power in omni-directional mode, and therefore the power level of DATA/ACK transmission is decided by a power reduction issue which is decided by the maximum interference. In line with the simulation results, important performance improvement has been achieved compared with a system using standard IEEE 802.11 protocol. Hence,the results indicate that the DPC protocol permits the network to dynamically win capacities near the best levels which is achieved by a system wherever the power control has been statically optimized.

13. **Modeling Energy Conservation**

    The energy conservation by the transmitter are mainly due to two main reasons: One reason is due to Radio Frequency (RF) generation and the electronics components that does the frequency synthesis, filter, conversion and so on. The RF frequency generation depends of the distance between the transmitter/receiver, modulation and this is the power generated by the antennas. One of the crucial decision while transmitting a packet is depends on the choice of the transmission power. The transmitter/receiver has its own power consumption P_{amp} and it depends on the architecture and process technology. The energy consumed during transmission is depends size of the packet, coding rate and P_{amp}. Similarly, the receiver can be either active or idle, by observing the channel. To receive the packets the receiver node also has the startup components and packet time. During the packet time, before the actual reception, the receiving circuitry is to be powered up that requires power.

2.7 Conclusion

This chapter offers the introduction of energy conservation techniques using numerous cross-layer style architectures. Completely different energy models exploitation programming methods, power management based, and multi-channel based protocol have been mentioned. The benefits and limitations of the models in energy conservation through multi-layer interaction are also addressed and discussed.