Abstract--Ad hoc networks are a key factor in the evolution of wireless communications. Self organized ad hoc networks of PDAs or laptops are used in disaster relief, conference, and battlefield environments. These networks inherit the traditional problems of wireless and mobile communications, such as bandwidth optimization, power control, and transmission- quality enhancement. In addition, their multi hop nature and the possible lack of a fixed infrastructure introduce new research problems such as network configuration, device discovery, and topology maintenance, as well as ad hoc addressing and self-routing. In this paper, we discuss five major categories of various Models provided in QualNet that is Battery, Radio Energy, Propagation, Antenna and Mobility models for Wireless Ad hoc Networks. Our work provides a sound starting point for further understanding and development of more realistic and accurate models for Wireless Ad hoc Network simulations.

Keywords--Ad-hoc Networks, Battery Models, Radio Energy, Propagation, Antenna, Mobility, QualNet

I. INTRODUCTION

In Wireless Ad hoc Networks, wireless hosts can communicate with each other in the absence of a fixed infrastructure [1]. These networks typically consist of equal nodes that communicate over wireless links without central control. Sensor networks, [2] also called hybrid ad hoc networks, are linked to monitoring centres that collect data such as temperature, chemical detection, or movement. In recent years, government agencies in several countries have supported research on sensor networks. For example, the US National Science Foundation launched a multidisciplinary program on sensors and sensor network research in 2003. Some ad hoc networks are linked to a fixed infrastructure via access points. For example, mesh or rooftop networks consist of antennas placed on top of buildings to provide wireless Internet access. Vehicles on a highway can create an ad hoc network for use in disseminating traffic information. They can operate as a pure ad hoc network in which an individual vehicle detects traffic events and initiates a broadcast to other vehicles. Alternatively, cellular or Internet access points placed near the road can transmit the information. Multi hop cellular networks3 have recently emerged as a communication alternative at events where huge numbers of users are concentrated in a small area such as a stadium. Peer-to-peer networks are ad hoc networks in which an overlay network is built on the Internet. In a P2P network, two or more peers can use appropriate information and communication systems to collaborate spontaneously without requiring central coordination.

Fig.1 various wireless networks mapped to two independent aspects of ad hoc networking: the level of centralized control (horizontal) and the use of radio multihopping (vertical).

Nowadays [2], many people carry numerous portable devices, such as laptops, mobile phones, PDAs and mp3 players, for use in their professional and private lives. For the most part, these devices are used separately that is, their applications do not interact. Imagine, however, if they could interact directly: participants at a meeting could share documents or presentations; business cards would automatically find their way into the address register on a laptop and
the number register on a mobile phone; as commuters exit a train, their laptops could remain online; likewise, incoming email could now be diverted to their PDAs; finally, as they enter the office, all communication could automatically be routed through the wireless corporate campus network. These examples of spontaneous, ad hoc wireless communication between devices might be loosely defined as a scheme, often referred to as ad hoc networking, which allows devices to establish communication, anytime and anywhere without the aid of a central infrastructure. Actually, ad hoc networking as such is not new, but the setting, usage and players are. In the past, the notion of ad hoc networks was often associated with communication on combat fields and at the site of a disaster area; now, as novel technologies such as Bluetooth materialize, the scenario of ad hoc networking is likely to change, as is its importance.

II. QUALNET SIMULATOR

The QualNet communications simulation platform QualNet is a planning, testing and training tool that "mimics" the behaviour of a real communications network. Simulation is a cost-effective method for developing, deploying and managing network-centric systems throughout their entire lifecycle. Users can evaluate the basic behaviour of a network, and test combinations of network features that are likely to work. QualNet provides a comprehensive environment for designing protocols, creating and animating network scenarios, and analyzing their performance. QualNet [3] is a comprehensive suite of tools for modelling large wireless and wired networks. It uses simulation and emulation process to predict the behaviour and performance of networks to improve their design, operation & management. It enables users to design new protocols, optimize new and existing protocols, designing of large wired and wireless networks using preconfigured or user-designed models, analyzing the performance of networks and perform what-if analysis to optimize the results. QualNet is a commercial product that grew out of GloMoSim simulator and it is distributed by Scalable Network Technologies. QualNet simulator is C++ language based tool. All the protocols are implemented in a series of C++ files and are called by the simulation kernel. QualNet simulator comes with java based graphical user interface (GUI). The QualNet Simulator has a scalable network library and provides accurate and efficient execution [7].

A. QualNet Applications

QualNet design new protocol models. It optimizes new and existing models and design large wired and wireless networks using pre-configured or user-designed models, also Analyze the performance of networks and perform what-if analysis to optimize them.

B. QualNet Components

QualNet Architect: A graphical scenario design and visualization tool. In Design mode, you can set up terrain, network connections, subnets, mobility patterns of wireless users, and other functional parameters of network nodes. You can create network models by using intuitive, click and drag operations. You can also customize the protocol stack of any of the nodes. You can also specify the application layer traffic and services that run on the network. In Visualize mode, you can perform in-depth visualization and analysis of a network scenario designed in Design mode. As simulations are running, users can watch packets at various layers flow through the network and view dynamic graphs of critical performance metrics. Real-time statistics are also an option, where you can view dynamic graphs while a network scenario simulation is running [3].

QualNet Analyzer: A statistical graphing tool that displays hundreds of metrics collected during simulation of a network scenario. You can choose to see pre-designed reports or customize graphs with your own statistics. Multi-experiment reports are also available. All statistics are exportable to spreadsheets in CSV format.

QualNet Packet Tracer: A graphical tool that provides a visual representation of packet trace files generated during the simulation of a network scenario. Trace files are text files in XML format that contain information about packets as they move up and down the protocol stack.

QualNet File Editor: A text editing tool

QualNet Command Line Interface: Command line access to the simulator

C. Key Features of QualNet

**Speed**-QualNet can support real-time speed to enable software-in-the-loop, network emulation, and human-in-the-loop modelling. Faster speed enables model developers and network designers to run multiple “what-if” analyses by varying model, network, and traffic parameters in a short time.

**Scalability**-QualNet can model thousands of nodes by taking advantage of the latest hardware and parallel computing techniques. QualNet can run on cluster, multi-core, and multi-processor systems to model large networks with high fidelity.

**Model Fidelity**-QualNet uses highly detailed standards-based implementation of protocol models. It also includes advanced models for the wireless environment to enable more accurate modelling of real-world networks.

**Extensibility**-QualNet can connect to other hardware and software applications, such as OTB, real networks, and third party visualization software, to greatly enhance the value of the network model [3].

**Portability**-QualNet and its library of models run on a vast array of platforms, including Windows and Linux operating systems, distributed and cluster parallel architectures, and both 32- and 64-bit computing platforms. Users can now develop a protocol model or design a network in QualNet on their desktop or laptop Windows computer and then transfer it to a powerful multi-processor Linux server to run capacity, performance, and scalability analyses.
III. CLASSIFICATION OF QUALNET MODELS

Models are broadly classified into five categories: Battery Models, Radio Energy Models, Propagation Models, Antenna Models and Mobility Models. Table 1 shows various Models that are to be discussed in this paper and the categories to which they belong.

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A. Battery Models

Battery models capture the characteristics of real-life batteries, and can be used to predict their behaviour under various conditions of charge/discharge. Battery models are useful tools for a battery-driven system design approach, because they enable analysis of the discharge behaviour of the battery under different design choices (e.g., system architectures, power management policies, and transmission power control), without resorting to time consuming (and expensive) prototyping and measurement for each alternative [4].

![System Level Block of Smart Batteries](image)

The total energy consumed by the system per cycle is the sum of energies consumed by the radio transceivers ($E_{Trans}$), the DC-DC converter ($E_{DC}$) and the efficiency losses in the battery ($E_{Bat}$)

$$E_{Cycle} = E_{Trans} + E_{CPU} + E_{DC} + E_{Bat} \quad (1)$$

1) Precise Service Life Estimator

The employed battery model is a modular approach for enhancing event-driven simulator with precise high-level battery level which can accurately estimate service life of a battery-operated device with a given-time-varying load. Moreover, our methodology has tightly coupled component models thus making our approach more accurate. Performance and energy computed by our simulator are within a few percent tolerances of hardware measurements on the Smart Badge. We employed the battery model developed by Sarma and Rakhmatov in eq. (1). Rakhmatov model was selected because it is the most accurate analytical model. The other models required solving Partial Differential Equations (PDEs) etc., which are difficult to optimize [5].

Parameter Estimation: Recall that Rakhmatov’s model is an abstraction of a real battery. For the model to adequately mimic real behaviour of the batteries we need to choose the appropriate parameters, so that predicted and observed lifetimes match closely. Thus, before one can use the proposed model, the parameters and need to be estimated from experimental data for the modelled battery. Simple experiments with constant loads are sufficient for estimation purposes, and one can utilize the following equation:
For a given battery under a given load, the battery voltage changes over time from the open-circuit value, $V_{\text{open}}$, to some cut-off value, $V_{\text{cutoff}}$. The observed lifetime is defined as the time when the battery voltage reaches $V_{\text{cutoff}}$. The predicted lifetime is defined as the time value for which the equality (2) holds. For a given set of constant loads $\{I(1), I(2), \ldots, I(M)\}$, the corresponding set of observed lifetimes is $\{L(1), L(2), \ldots, L(M)\}$. The objective is to find and such that the predicted lifetimes match the observed lifetimes as closely as possible. However, this objective is hard to pursue directly, since (2) is hard to solve for the unknown $L$. Alternatively, one can estimate parameters by fitting the load values for a given set of observed lifetimes. Let denote the fitted value of $I(k)$. According to eq. (1):

$$I(k) \approx \frac{\alpha}{L(k) + 2 \sum_{m=1}^{10} \frac{1-e^{-\beta m^2 L}}{\beta^2 m^2}}$$

(3)

The objective now is to find such that matches $I(k)$ as closely as possible for all. One can employ a standard least-squares estimator for this purpose: the model parameters are selected so that is minimized. In summary, to implement this model you need to follow these steps:

$$\sum_{k=1}^{M} |\hat{I}(k) - I(k)|$$

Get the data sheet of a battery that models rated capacity (in Ahr) vs. discharge current (in hour). Do the curve fitting to get $\beta$ parameters for Rakhmatov’s model. Use the optimized model to generate pcm file. The semantics of pcm file is excess consumption versus time, and each entry represents time interval of one second. That is, first line means: “after one second, if a unit load is applied the battery will be drained by X amount”. Notice that the excess amount decreases as time increases and asymptotically reaches 1 [5].

2) Precise Residual Life Estimator

One important characteristic of the battery is that some amount of energy will be wasted when the battery is delivering the energy required by the circuit. In analytical form, given a fixed battery output voltage, if the circuit current requirement for the battery is $I$, the actual current that is taken out of the battery is $I_{\text{bat}}$.

$$I_{\text{act}} = \frac{I_{\text{bat}}}{\mu}, \ 0 < \mu \leq 1$$

(4)

Where is called the battery efficiency (or utilization) factor. $I_{\text{act}}$ is always larger than or equal to $I_{\text{bat}}$. Defining $\text{CAP}^0$ as the amount of energy that is stored in a new (or fully charged) battery and $\text{CAP}^\text{act}$ as the actual energy that can be used by the circuit, (4) is equivalent to:

$$\text{CAP}^\text{act} = \mu \text{CAP}^0$$

The efficiency factor is a function of discharge current $I_{\text{bat}}$:

$$\mu = f(I_{\text{bat}})$$

Where $f(.)$ is a monotonic-decreasing function. Only the low-frequency part of the current is relevant to changing the battery efficiency. Therefore, $I_{\text{bat}}$ must be the average output current of the battery (denoted by $i(t)$) over certain amount of time, which can be represented as $N.T$, where $N$ is some positive integer and $T$ is the clock cycle. $N.T$ may be as large as a few seconds [4].

$$I_{\text{bat}} = \frac{1}{N \cdot T} \int_{0}^{N \cdot T} i(t) \cdot dt$$

(5)

The actual capacity of the battery decreases when the discharge current increases.

3) Linear Model

This model is a simple linear model which is based on the coulomb counting technique [5]. The coulomb counting technique accumulates the dissipated coulombs from the beginning of the discharge cycle and estimates the remaining capacity based on the difference between the accumulated value and a pre-recorded full-charge capacity. This method can lose some of its accuracy under variable load condition because it ignores the non-linear discharge effect during the coulomb counting process.

**Implemented Features:** Implementation of a model for accurate estimation of service life of a battery. This model captures the following contributing factors:
Battery rate capacity effect: the model which precisely estimates non-linearity effect of rated capacity versus discharge current load.

Charge recovery effect: the model takes into account the actual phenomenon that battery charge increases when no discharge current load is drawn from the battery for a given period of time. Implementation of a model for fairly good prediction of remaining residual life of the battery. The model captures non-linearity of rated capacity versus discharge current load by introducing utilization function. Implementation of a simple linear model based on the Columbus Count method. In this method the battery is discharged linearly over its service life and the rate of discharge at any time is the current which is drawn from battery [5].

Battery charge level monitoring: The state of charge of the charge of the batteries attached to a battery-operated node is periodically checked and if the battery is out of charge the node is shut down (currently inserting permanent faults on all network interfaces attached to the node).

User configurable battery type: the model developed in the simulator is a generic and parametric model. For the model specification the input parameters must be configured initially for a given battery-type from a battery manufacturer.

B. Radio Energy Models

The issue of energy saving is significant since in a battery-operated wireless node, the battery energy is finite and a node can only transmit a finite number of bits. The maximum number of bits that can be sent is defined by the total battery energy divided by the required energy per bit. Most of the pioneering research in the area of energy-constrained communication has focused on transmission schemes to minimize the transmission energy per bit. The Radio Energy Models [6] reads the energy consumption specifications of the radio where the specifications are defined by the configuration parameters which are the power supply voltage of the radio, electrical current load consumed in Transmit, Receive, Idle, and Sleep modes. Each state represents a different level of energy consumption.

Transmit: node is transmitting a frame with transmission power Ptx.

Receive: node is receiving a frame with reception power Prx. That energy is consumed even if the frame is discarded by the node because it was intended for another destination, or it was not correctly decoded.

Idle: Even when no messages are being transmitted over the medium, the nodes stay idle and keep listening the medium with Pidle.

Sleep: when the radio is turned off and the node is not capable of detecting signals. No communication is possible. The node uses Psleep that is largely smaller than any other power [7].

1) Radio Specific Energy Model

The model reads the energy consumption specifications of the radio where the specifications are defined by the configuration parameters which are the power supply voltage of the radio, electrical current load consumed in Transmit, Receive, Idle, and Sleep modes. From the radio interface data sheets provided by the vendors of the wireless interfaces, we have stored the specifications of several commonly used wireless interfaces such as given the name of vendor as configuration parameter, the energy model specifications are loaded for that wireless interface [5].

2) Generic Radio Energy Model

The generic model has been derived from the equations and the modules presented in the previous section. The main feature of the model is estimation of energy consumption for the radios with common modulation schemes (analogue and digital) and common classes of amplifiers (class-A, B, C, D). Furthermore, the model can estimate energy consumption in transmitter for the case of continuous transmits power level. The parameters which are optionally required for generic model to be able to more accurately estimate the power or the amount of current loaded on battery are [7]: Amplifier drain efficiency, Peak to average power ratio (PAR), the power supply voltage Vdd, Idle power consumption, Sleep power consumption, Psleep. The default value is 0 mW.

3) Mica Motes Radio Energy Model

The Mica Motes radio energy model is a radio-specific energy model which is pre-configured with the specification of power consumption of Mica motes (embedded sensor nodes) [7]. A MICA mote is a commercially available product that has been used widely by researchers and developers. MICA motes are available to the general public through a company called Crossbow. The MICA mote uses an Atmel at mega 128L processor running at 4 megahertz which is an 8-bit microcontroller that has 128 kilobytes of onboard flash memory to store the mote’s program. This CPU is about as powerful as the 8088 CPU found in the original IBM PC (circa 1982). The big difference is that at mega consumes only 8 milliamps when it is running, and only 15 micro amps in sleep mode [8]. MICA motes come with 512 kilobytes of flash memory to hold data. They also have a 10-bit A/D converter so that sensor data can be digitized. The final component of a MICA mote is the radio. It has a range of several hundred feet and can transmit approximately 40,000 bits per second.

4) MICA Z

The MicaZ radio energy model is a radio-specific energy model which is pre-configured with the specification of power consumption of MicaZ motes (embedded sensor nodes). The MICA Z is a 2.4 GHz Mote module used for enabling low-power, wireless sensor networks. As MICA MOTE is a 3rd generation device used for enabling low power, WSN available in 2.4 GHz and 868/916 MHz, MICA Z offer a 2.4 GHz, IEEE/ZIGBEE 802.15.4 and is a tiny Wireless Measurement System. It is specifically designed for deeply embedded sensor networks. Maximum data rate is 250 Kbps;
modulation schemes used are O-QPSK. Transmit and receiving power is 19 and 17mA [8]. Some of the important applications are:
Indoor Building Monitoring and Security, Acoustic, Video, Vibration and Other High Speed Sensor Data, Large Scale Sensor Networks (1000+ Points).

C. Propagation Models
In this section, we explore both concepts of Large-scale Path Loss and Fading. We introduce three models of Large-scale Path Loss which account for the large-scale attenuation of signal based on distance: Free-Space, Two-Ray and Lognormal Shadowing. As will be presented hereafter, however, the level of sophistication and the inclusiveness of the models increase from the simple model of Free-space to the more realistic model of Shadowing. On the other hand, Fading is the phenomenon responsible for rapid fluctuations of signal over a short period of time or distance [9].

1) Free-Space Model
This model is used to predict the signal strength when the transmitter and the receiver have a clear, unobstructed line-of-sight (LOS) path between them. It predicts that the received power decays as a function of Transmitter-Receiver distance rose to some power, typically to the second power.

2) Two-Ray Model
This model, which is a more realistic model than the Free-Space model, addresses the case when we consider a ground reflected propagation path between transmitter and receiver, in addition to the direct LOS path. This model is especially useful for predicting the received power at large distances from the transmitter and when the transmitter is installed relatively high above the ground [9].

3) Log-Normal Shadowing Model
The empirical approach for deriving radio propagation models is based on fitting curves or analytical expressions that recreate a set of measured data. Adopting this approach has the advantage of taking into account all the known and unknown phenomena in channel modelling [9]. A widely-used model in this category is Log-normal Shadowing. In this model, power decreases logarithmically with distance. The average loss for a given distance is expressed using a Path Loss Exponent. For taking into account the fact that surrounding environmental clutter can be very different at various locations having the same Transmitter-Receiver distance, another parameter is incorporated in the calculation of path loss.

4) Fading Models
The term fading is used to describe the rapid fluctuations of the amplitudes, phases, or multipath delays of a signal over a short period of time or distance. It is caused by interference between multiple versions of the transmitted signal which arrive at the receiver at slightly different times [10]. Hence, the resulting signal at the receiver may have a wide-varying amplitude and phase. In short, the effects of multipath are rapid changes in signal strength over a small travel distance or time interval, random frequency modulation due to varying Doppler shifts on different multipath signals and time dispersion caused by multipath propagation delays.

Rayleigh Fading Model: Rayleigh fading model is a statistical model to represent the fast variation of signal amplitude at the receiver. In wireless propagation, Rayleigh fading occurs when there is no line of sight between the transmitter and receiver [10]. The fading speed is affected by how fast the receiver and/or transmitter, or the surrounding objects are moving. QualNet’s Rayleigh fading model uses pre-computed time series data sequence with different sample intervals to represent the different fading speeds or coherence times of the propagation channel.

Ricean Fading Model: Ricean fading model is a statistical model to represent the fast variation of signal amplitude at the receiver. In wireless propagation, Ricean fading occurs when there is line of sight between the transmitter and receiver, and the line of sight signal is the dominant signal seen at the receiver [10].

D. Antenna Models
QualNet supports three standard antenna models: Omni-directional, switched-beam, and steerable. The antenna gain for the Omni-directional antenna is the same in all directions. For switched-beam and steerable antennas, the antenna gains in different directions are read from the azimuth pattern file and (optionally) the elevation pattern file. These pattern files are specified using the traditional format. The antenna model file can also be used for defining customized Omni-directional, switched-beam, and steerable antenna models. In this case, a set of values for the antenna parameters (gain, height, efficiency, different losses, and azimuth and elevation pattern files) are associated with an antenna model name. This name can be used in the scenario configuration file to assign an antenna model to an interface [11].

1) Omni Directional Antenna Model
The Omni directional antenna is the basic antenna which yields the same antenna gain irrespective of the direction of the transmitted or received signal [5].

2) Steerable Antenna Model
The steerable antenna is a special type of patterned antennae. A patterned antenna has different gains in different directions. The values of the gain in different directions follow a gain pattern. The steerable antenna can rotate the antenna and uses the direction that yields the maximum antenna gain [5].
3) Switched-Beam Antenna Model
The switched-beam antenna is a special type of patterned antenna [5]. A patterned antenna has different gains in different directions. The values of the gain in different directions follow a gain pattern. A switched beam antenna can utilize multiple antenna patterns.

E. Mobility Models
In this model sensor nodes are dynamic and pan co-coordinator are static. In the performance evaluation of a protocol for a wireless sensor network, the protocol should be tested under realistic conditions including, but not limited to, a sensible transmission range, limited buffer space for the storage of messages, representative data traffic models [12], and realistic movements of the mobile users (i.e., a mobility model). This model is a journey through mobility models that are used in the simulations of mobile Ad-hoc sensor networks. Here the descriptions of mobility models that represent mobile nodes whose movements are independent of each other (i.e., entity Mobility models) and mobility models that represent mobile nodes whose movements are dependent on each other.

1) File-Based Mobility Model
The file-based mobility model uses waypoints for each node specified by the user in a node position file. Each waypoint is a specification of a node’s location and (optionally) orientation and the time at which the node arrives at that location. The node moves from one waypoint to the next in a straight line at a constant speed [5]. For each node, the node positions should be sorted (in ascending order) by simulation time. Each node position specification should be on a single line by itself. Comments can be entered anywhere in the node position file.
2) Random Waypoint Mobility Model

It assumes that nodes move in an open field without obstructions. In contrast, the layout of roads, intersections with traffic signals, buildings, and other obstacles in urban settings constrain vehicular movement. In response to the limitations of RWM, more researchers have become interested in modelling ‘realistic’ mobility patterns for VANETs [12].

![Fig.6 Travelling Pattern of Mobile Node Using Random Waypoint Mobility Model](image)

3) Group Mobility Models

Group Mobility models are to simulate group movement behaviours in the real world [12]. These mobility models tend to mimic motions of the mobile nodes in mobile Ad-hoc networks where communications are done among teams that coordinate their movements. The group movements imply that mobile nodes work together in a cooperative manner in order to accomplish a common goal. Many Group Mobility Models exist, but here we will be discussing only Reference Point Group Mobility Model.

**Reference Point Group Mobility Model:**

In Reference Point Group Mobility model, nodes form a group and then move in a coordinated manner. It is represented using 4-tuple: \((V_{\text{max}}, T, R_{\text{max}}, V_{i})\); where \(V_{\text{max}}\) is maximum speed, \(R_{\text{max}}\) is the maximum allowable range within the group from group logical centre, \(T\) is pause time and \(V_i\) is the advance direction vector. Each group has a logical centre, called group leader, which determines the group’s behaviour [12]. Initially, each member of the group is uniformly distributed in the neighbourhood of the group leader. The motion of the group leader completely characterizes the movement of its corresponding group of mobile nodes, including their direction and speed. Individual mobile nodes randomly move about their own pre-defined reference points whose movements depend on the group movement.

![Fig.7 travelling pattern of 3 mobile nodes using Reference Point Group Mobility Model](image)

IV. CONCLUSION

Major five categories of Various Models provided in QualNet are described for Wireless Ad hoc networks. We also provided a large overview of actual models available to the research community in Wireless Ad-hoc Networks. We illustrated that today’s trend is to go toward an increased realism. We additionally depicted the overview on the Network Simulator QualNet and discussed its various applications, components and key features.

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