Overview

The TELEGRID Proteus wireless mesh network is an ad-hoc, self-forming mesh network based on the 802.11/b/g/n IEEE standard which operates in the 2.4 and 5.8 GHz frequency bands. An Ad-hoc network is a collection of autonomous nodes that operate without a centralized access point or existing infrastructure. Ad-hoc networks are self-forming and self-healing and therefore, do not rely on the centralized services of a single node. Nodes in an ad-hoc network forward data from themselves or for other nodes to form an arbitrary network topology. The PROTEUS network can be used for in a static architecture for use in unattended ground sensors as well as mobile applications where the network topology is unpredictable.

Routing Protocol

The TELEGRID Proteus network uses an implementation of the Better Approach to Mobile Ad hoc Networking (B.A.T.M.A.N) routing protocol. B.A.T.M.A.N. is a routing protocol for multi-hop mobile ad hoc networks which was developed by the German "Freifunk" community and intended to replace the Optimized Link State Routing protocol (OLSR). In OLSR, there is a serious synchronization problem between the topology messages and the routing information stored inside every node. This caused a mismatch between what is currently stored in the routing tables and the actual topology of the network. This is due to the propagation time of the topology messages which caused infinite routing loops are the main effect of such problems.

This caused OLSR to have significant performance shortcomings when the number of nodes in the network grew too large (approx. 300+ nodes) and so B.A.T.M.A.N was created specifically for large ad-hoc mesh networks.

In BATMAN, there is no topology message dissemination. Every node executes the following operations.

1. Sending of periodic advertisement messages, called OriGinator Message (OGM). The size of these messages is just 52 bytes, containing: the IP address of the originator, the IP address of the forwarding node, a Time To Live (TTL) value and an increasing Sequence Number (SQ).
2. Checking of the best one-hop neighbor for every (known) destination in the network by means of a ranking procedure.
3. Re-broadcasting of OGMs received via best one-hop neighbor.

The BATMAN uses a timer for sending OGMs and SQ (OGM) for checking the bi-directionality of links. If the SQ of an OGM received from a particular node falls within a certain range then the corresponding link is considered to be bi-directional.

For example, suppose that in a time interval *T*, node A sends *Tr* messages, where r is the rate of OGM messages. The neighbors of A will re-broadcast the OGMs of A and also other node’s OGMs. When A receives some OGMs from a neighbor node, say B, it checks if the last received OGM from B has an SQ less than or equal to *Tr*. If it does, then B is considered to be bi-directional, otherwise it is considered to be unidirectional. Bi-directional links are used for the ranking procedure. The quantity *Tr* is called the bi-directional sequence number range. The ranking procedure is a substitute of the link quality extension of OLSR.

In a few words, every node ranks its neighboring nodes by means of a simple counting of total received OGMs from them. The ranking procedure is performed on OriGinator (OG) basis, i.e. for every originator. Initially, for every OG, every node stores a variable called Neighbor Ranking Sequence Frame (NBRF), which is upper bounded by a particular value called the ranking sequence number range. We suppose that there is a rank table in every node which stores all the information contained in the OGMs. Whenever a new OGM is being received via a bi-directional link, the receiving node executes the following steps.

1. If the sequence number of the OGM is less than the corresponding NBRF, then drop the packet.
2. Otherwise, update the NBRF = SQ (OGM) in the ranking table.
3. If SQ (OGM) is received for the first time, store OGM in a new row of the rank table.
4. Otherwise, increment by one the OGM count or make ranking for this OGM.

Finally, the ranking procedures select the best one-hop neighbor (the neighbor which has the highest rank in the ranking table). Let us note that the same OGM packet is used for: link sensing, neighbor discovery, bi-directional link validation and flooding mechanism. While this feature eliminates routing loops because no global topology information are flooded, the self-interference due to data traffic can cause oscillations in the throughput as we will see in our experiments.

In BATMAN, every node re-broadcasts received OGMs only once, and only those OGMs, which have been received via the best-ranked neighbor. This is a kind of selective flooding, which practically reduces the overhead of the flooding. Another analogy can be found in gossip protocols. In gossip protocol, every node decides to re-broadcast received data with some probability *p*. This is equivalent to eliminating some links in the network and then supposing that every node re-broadcast with probability 1. In gossip protocol, there is a threshold for *p* and the density of nodes after which the success ratio is almost surely 1. In BATMAN, the probability *p* is changed according to the ranking procedure. It is the probability that an OGM is reached via the best rank neighbor. The expression of this probability is left for further analysis. Let us note that the selective flooding eliminates possible misbehavior of the ranking procedure. In fact, cumulative count of the OGM could be greater than the total number of OGM received via the current best neighbor.

The original B.A.T.M.A.N routing protocol implementations operate on ISO/OSI Layer 3 (Network Layer) and routing information is exchanged via UDP packets and routing decisions are accomplished by manipulating the kernel routing table.

The Proteus wireless mesh network expands on the original B.A.T.M.A.N routing protocol by implementing the Advanced protocol which operates on layer 2 (Ethernet layer). All routing information as well as data traffic is transported using raw ethernet frames. Network traffic is encapsulated and forwarded until it reaches the destination thereby emulating a virtual network switch of all nodes. All nodes are unaware of the network's topology and therefore unaffected by network changes.

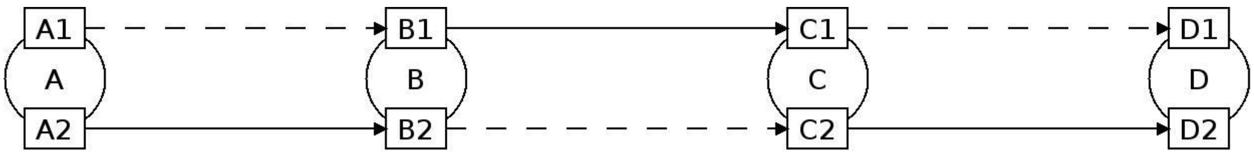
This architecture has the following advantage:

- network-layer agnostic – Can run IPv4, IPv6, DHCP, IPX
- Nodes <u>do not</u> require an IP address
- Integration and roaming of non-mesh (mobile) clients
- Data flow optimization
- Capable of broadcast/multicast over the mesh and non-mesh clients

Proteus Mesh Node Radio

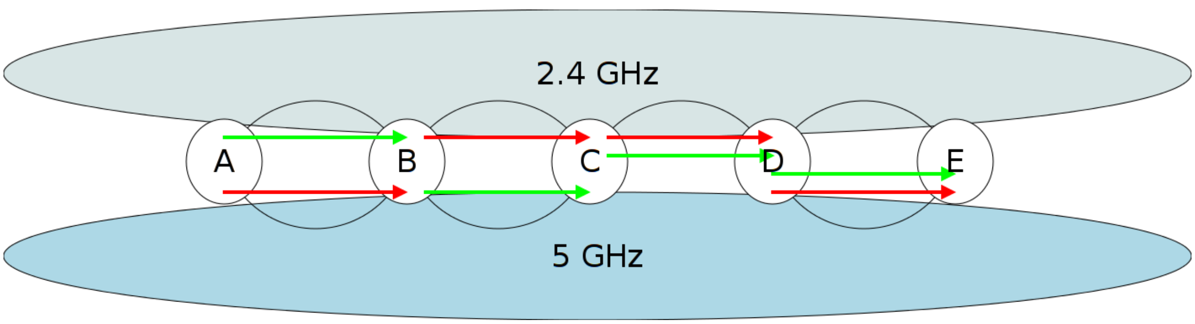
The Proteus nodes use multiple-input and multiple-output (MIMO) radios which is a technique for multiplying the capacity of a radio link using multiple transmit and receive antennas to exploit multipath propagation. In order to further enhance network transmission, the Proteus mesh nodes integrates two MIMO radios which can be configured to operate in the same or different frequency bands. Proteus radios can operate in the frequency bands of 900MHz, 2.4GHz and 5.8GHz.

The dual radio architecture allows the B.A.T.M.A.N. routing protocol to be configured for interface alternation. Interface alternation forwards frames on a different interface than on which the frame was received. The purpose of this alternation is to reduce the interference caused by the limitation of only sending or receiving on one Wi-Fi interface at one time. It also helps balance the network load on available interfaces which ultimately increases throughput. The mechanism is illustrated below for a chain of nodes with two interfaces.

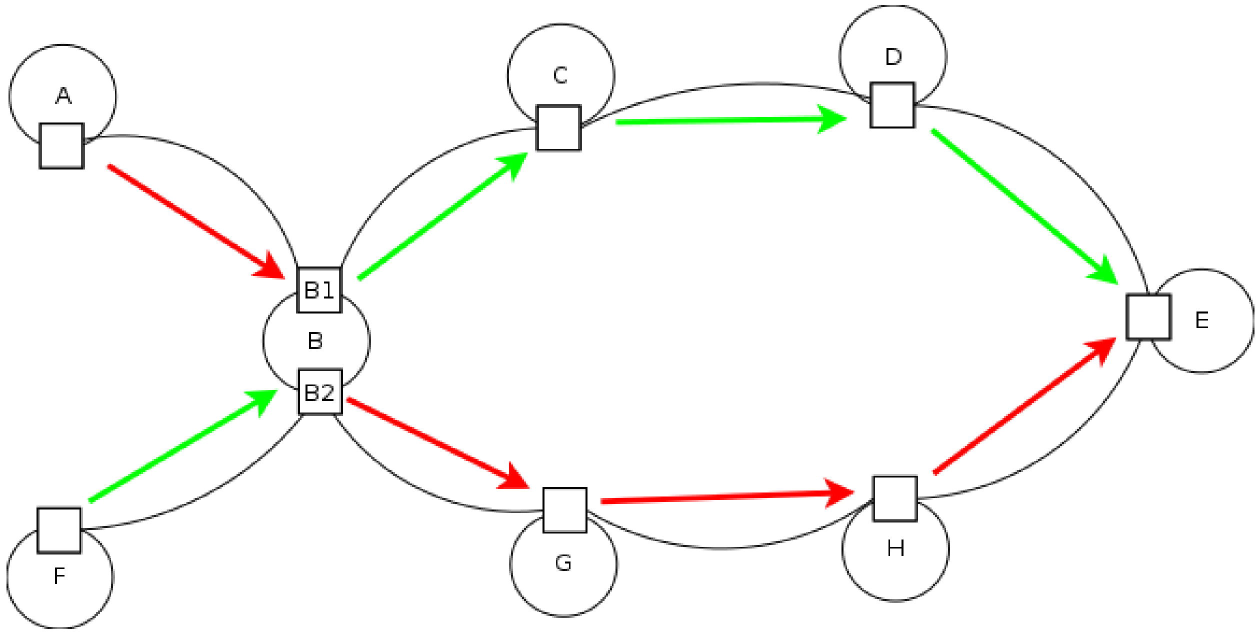


Interface alternating is performed by considering the interface where a packet has been received and choosing the best neighboring node of the available outgoing interfaces. On half-duplex interfaces like Wi-Fi forwarding decisions where sending and receiving interfaces are the same are considered worse and penalized to avoid possible selection.

B.A.T.M.A.N further improves on this approach by performing network wide interface alternating. The method makes the interface decision by considering the whole mesh network. In the example below, most nodes have both a 2.4 GHz and a 5.8 GHz link to the next hop, except for the connection between node C and D which only has a 2.4 GHz. Node A will now choose the 2.4 GHz link first to reach node E so it can avoid using the same frequency at node C.



With network-wide multi interface optimization a multi-interface node can act as a routing splitting point. In the example below node B will route the packets via C if they are coming from F (green path) and route the packets via G if they are coming from A (red path) for the destination E. This is different from the previous implementation since packets are routed based on the interface received rather than via the same path.



B.A.T.M.A.N V

The TELEGRID Proteus improves performance by using the B.A.T.M.A.N V Routing protocol version. In previous routing versions decision were made based on the least number of hops used to reach the final destination. This was based on original mesh routing protocols where hop throughput degradation was a concern and minimal hop traversal was of great importance. B.A.T.M.A.N virtually eliminates hop degradation and therefore forcing communication over a possible sporadic link only to ensure lowest hops can negatively affect the entire network. B.A.T.M.A.N V improves on this routing decision by allowing a throughput-based metric to be used in the routing decisions. This allows route selection to traverse multiple stable hops as long as best throughput is achieved.

ALFRED

The TELEGRID Proteus Wireless mesh network also uses the Almighty Lightweight Fact Remote Exchange Daemon (ALFRED). ALFRED is a user space daemon for distributing arbitrary local information over the mesh/network in a decentralized fashion. Proteus uses ALFRED to transmit sensor and GPS information.