Evaluation of the IEEE 802.16 Mesh MAC for Multihop Inter-ship Communications

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1. TRITON Project

**Background**
- High-speed networks are needed for communications in maritime environments:
  - General communications (for ship passengers and crew): Telephone, Internet
  - Management: seaport management, navigation
  - Safety: Piracy prevention, Tsunami alerting, Pollution detection, Terrorism prevention
  - Exploration: Sea source detection and exploration (oil, gas, mineral, fishery …), Ocean scientific research (seabed terrain detection …)
- However, current maritime communications are mainly based on satellites, which is expensive (e.g. around >USD 7/min) and relatively slow (e.g. 64kbps, 256kbps)

**Targets**
- The first target is to allow the shipping companies to get lower cost access on their current applications, like voice and fax, etc.
- The project will be able to enable new applications such as video surveillance, again, at a lower cost

**Partnership**
- Wireless Communications Laboratory, National Institute of Communications and Information Technology (NiCT @ Singapore)
- Network Technology Department, Institute for Infocomm Research (I²R), Singapore
2.1 Network Scenario in TRITON

- The envisaged network is a wireless multi-hop ad hoc network amongst ships, marine beacons and buoys.
- The multi-hop ad hoc network will be connected to the terrestrial networks via land stations at shore.
- It is a kind of VANET (Vehicular Ad Hoc Network), with different mobility pattern from terrestrial VANET and time-varying received signal quality and wave occlusions due to movements of sea surface.
- IEEE 802.16 mesh MAC is selected as WiMAX is the near future step for broadband wireless access.

2.2 Network Scenario in TRITON (cont.)

- Route redundancy with BS-SS range of 10 km and SS-SS range of 6.3 km.
- Route redundancy with BS-SS range of 10 km and SS-SS range of 10 km.

The region of interest

A snapshot of ship locations within the region of interest.
3. IEEE 802.16 mesh MAC

- IEEE 802.16 has two operation modes:
  - Point-to-multipoint (PMP) mode: conventional cellular network
  - MESH mode: multi-hop connections
- TDMA frame
- Management messages: NENT, NCFG, DSCH
- Bandwidth application: request – grant – confirm
- ARQ supported
- Mobility is not supported

<table>
<thead>
<tr>
<th>Time</th>
<th>Frame n-1</th>
<th>Frame n</th>
<th>Frame n+1</th>
<th>Frame n+2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network entry</td>
<td>Network config</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>NENT, NCFG, DSCH</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

4. Maritime Communication Environment

- By our measurements, two-ray path loss model is applicable in maritime environment for IEEE 802.16 interested frequencies, like at 2.4 GHz
- Drop of signal strength can be as high as 20 dB due to blocking of big ships
- Time-varying signal strength, due to time-varying antenna high, signal arriving angle, reflection of the rough sea surface, and block of ocean wave
- Signal receiving very much depends on sea states:
  - Sea states: a description of roughness of sea surface
  - Different sea states have different periods, ocean wave lengths, ocean wave heights
- What will happen for message transmission on MESH MAC when signal strength varies? – Received signal is lower than receiver sensitivity:
  - Signal is treated as interference and signal will be drop
  - If signal is management message like NENT, NCFG, DSCH
    - NENT: network entry failed
    - NCFG: neighboring information missed, hide-node problem arise
    - DSCH: bandwidth application failed – data transmission delay, data transmission conflict
  - If signal is data message: ARQ – data transmission delay, drop of MAC packets
5.1 Simulation Setup/Implementation

maritime simulator: two ray model in sea, time-varying sea terrain corresponding to each sea state, ship mobility model, and WiMAX mesh MAC

<table>
<thead>
<tr>
<th>Simulation Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulation</td>
<td>QPSK, ½ rate coding</td>
</tr>
<tr>
<td>Frame</td>
<td>duration 5 ms, 10 ms, 20 ms</td>
</tr>
<tr>
<td></td>
<td>number of slots 250</td>
</tr>
<tr>
<td></td>
<td>persistence 1, 7</td>
</tr>
<tr>
<td>Sea states</td>
<td>1.0 (P, H, L) 1.5 s, 0.15 m, 2.9 m</td>
</tr>
<tr>
<td></td>
<td>3.0 (P, H, L) 3.5 s, 1.07 m, 14.02 m</td>
</tr>
<tr>
<td></td>
<td>5.0 (P, H, L) 5.5 s, 2.44 m, 32 m</td>
</tr>
<tr>
<td></td>
<td>7.0 (P, H, L) 9.9 s, 7.62, 100.13 m</td>
</tr>
<tr>
<td>CBR source</td>
<td>packet size 256 bytes, 512 bytes, 1024 bytes</td>
</tr>
<tr>
<td></td>
<td>packet interval 5 ms, 10 ms, 20 m s</td>
</tr>
<tr>
<td>Routing protocol</td>
<td>AODV</td>
</tr>
<tr>
<td>Ship size (SL, SW, SH)</td>
<td>64 m, 8 m, 16 m</td>
</tr>
<tr>
<td>Antenna (horizontal, vertical)</td>
<td>Omnidirectional, 9-degree beamwidth</td>
</tr>
</tbody>
</table>

P: wave period; H: wave height; L: wave length; SL: ship length; SW: ship width; SH: ship height

5.2 Simulation Setup/Implementation (cont.)

Wave direction

Link direction

(a) parallel (0°)

(b) perpendicular (90°)

No mobility
5.3 Simulation Setup/Implementation (cont.)

6.1 Throughput versus sea states with parameters of connection distance and link direction, for 1-hop CBR connections
6.2 Delivery ratio versus sea states with parameters of connection distance and link direction, for 1-hop CBR connections.

![Graph showing delivery ratio versus sea states with connection distance and link direction.]

6.3 Average delay versus sea states with parameters of connection distance and link direction, for 1-hop CBR connections.

![Graph showing average delay versus sea states with connection distance and link direction.]

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6.4 Throughput versus sea states with parameters of hop count and link direction.

![Throughput graph]

6.5 Delivery ratio versus sea states with parameters of hop count and link direction.

![Delivery ratio graph]
6.6 Average delay versus sea states with parameters of hop count and link direction.

![Graph showing average delay versus sea states](image)

6.7 Throughput versus number of 1-hop CBR data follows, with parameter of sea states

![Graph showing throughput versus number of flows](image)

- 30 IEEE 802.16 MESH nodes
- Each data flow source: 50 kB/s CBR
7. Conclusions and Future Work

- An IEEE 802.16 MESH network is envisaged for multihop inter-ship communications

- Simulation shows that:
  - When sea wave direction is perpendicular to the nodes link direction, in both 1-hop and 2-hop links, packets delivery ratio can be 100% and throughput can be 50 kB/s, and in all sea states investigated the MAC performance remains almost the same
  - When sea wave direction is same as the nodes link direction, in both 1-hop and 2-hop links, in sea states 1.0 and 3.0, packets delivery ratio can be 100% and throughput can be 50 kB/s; in sea states 5.0 and 7.0, the throughput, delivery ratio and average delay become worse
  - With more data flows and higher sea states, the increase in network throughput becomes slower due to increased 2-hops transmission and longer disconnected period

- Future work includes:
  - MESH MAC performance when have traffic of voice, video, web ..
  - MESH MAC performance in mobile case