# Experimental Evaluation of RF Modems used in Fleets of Multiple Cooperating Autonomous Undersea Vehicles

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# Outline

- Motivation and background
- RF modems used in the experiments
- Experiment methodology
- Experiment results
- Conclusions and future work

# Motivation and Background

- RF modems are used for communication among multiple surfaced cooperating autonomous undersea vehicles (AUVs), gateway buoys, and land or ship based operators.
- RF modems are inherently more complex than their wired counterparts which makes it difficult to estimate the performance.
- Goals:
  - to set realistic expectations of RF modem performance
  - to aid in the design of comprehensive communication solutions for AUVs.

# RF Modems


*FreeWave*

FGR-115RC


*MaxStream*

XTend-PKG-U

*NovaRoam*

EH900

# RF Modem Overview

| | *FreeWave* | *MaxStream* | *NovaRoam* |
|---|---|---|---|
| Manufacturer | FreeWave Tech. | MaxStream | Nova Eng. |
| Model | FGR-115RC | XTend-PKG-U | EH900 |
| Dimensions (mm) | $165 \times 74 \times 57$ | $140 \times 70 \times 29$ | $160 \times 132 \times 33$ |
| Weight (g) | 441 | 200 | 400 |
| Band | 900 MHz ISM | 900 MHz ISM | 900 MHz ISM |
| Transmit power | 5 mW – 1 W | 1 mW – 1 W | 10 mW – 1 W |
| RF data rate | 9600/19200 bps | 9600/115200 bps | 100/400 kbps |
| Host interface | serial | USB | Ethernet/ser. |
| Multi-hop routing | static | no | dynamic |

# RF Modem Characteristics

- *Host Interfaces*:
  - Serial (RS232), serial over USB, and Ethernet
  - Host interface has no significant impact on the performance.
- *Multi-hop Communication*:
  - *FreeWave*: static multi-hop routing
    - Routes are set up using modem management.
    - No automatic re-routing on path failure
  - *NovaRoam*: dynamic multi-hop routing
    - AODV ad hoc routing protocol
    - Entire wireless network forms a single IP subnet.

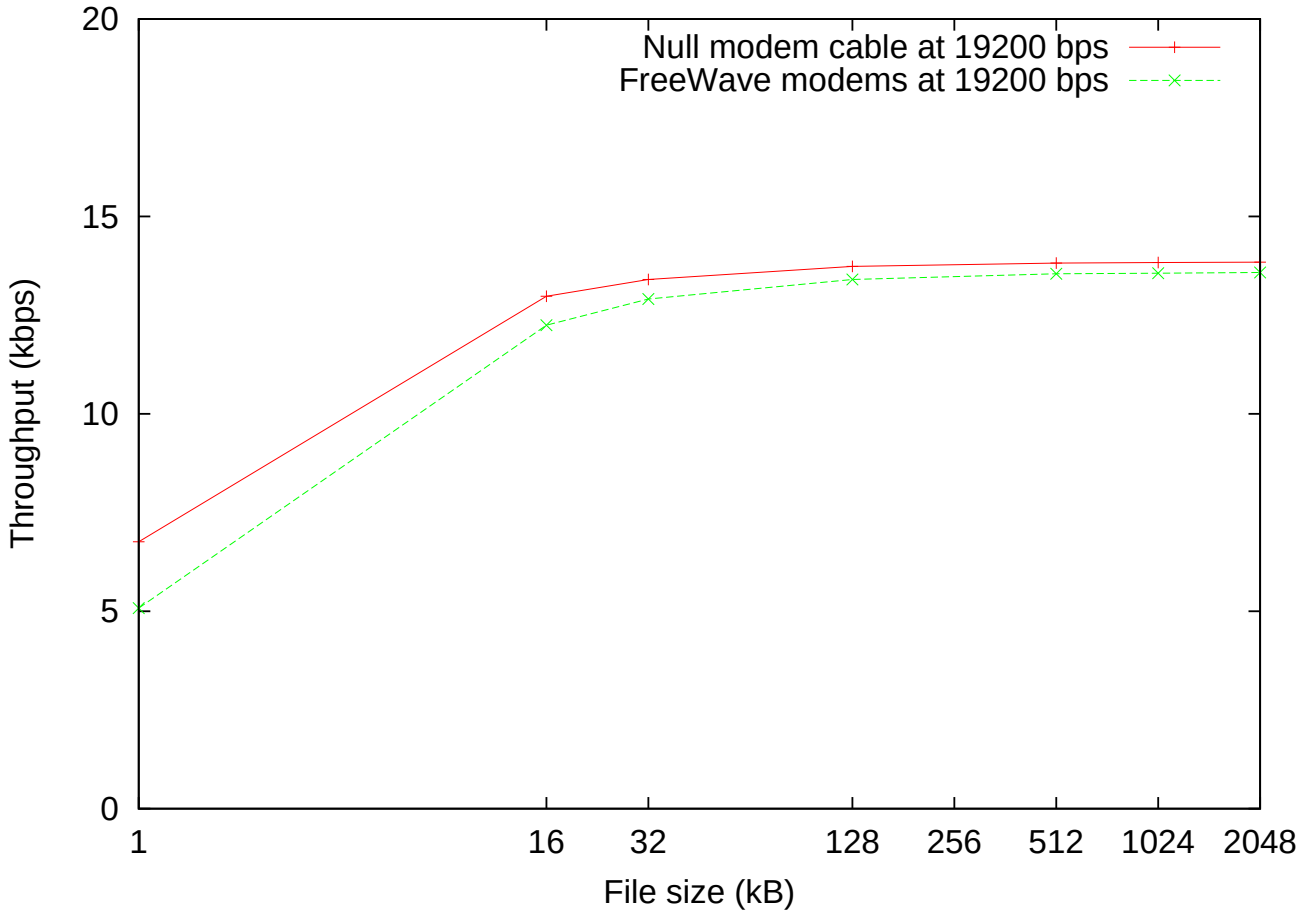
# RF Modem Configuration and Management

- *FreeWave*:
  - Simple menu-based configuration mode
  - Difficult to switch to the configuration mode
- *MaxStream*:
  - Rich set of AT commands
  - Binary control mode
  - A Windows-based management application
- *NovaRoam*:
  - Web-based configuration only
  - JavaScript pages that do not work in the current version of Firefox browser.
  - No reset button on the modem.

# Experiment Methodology

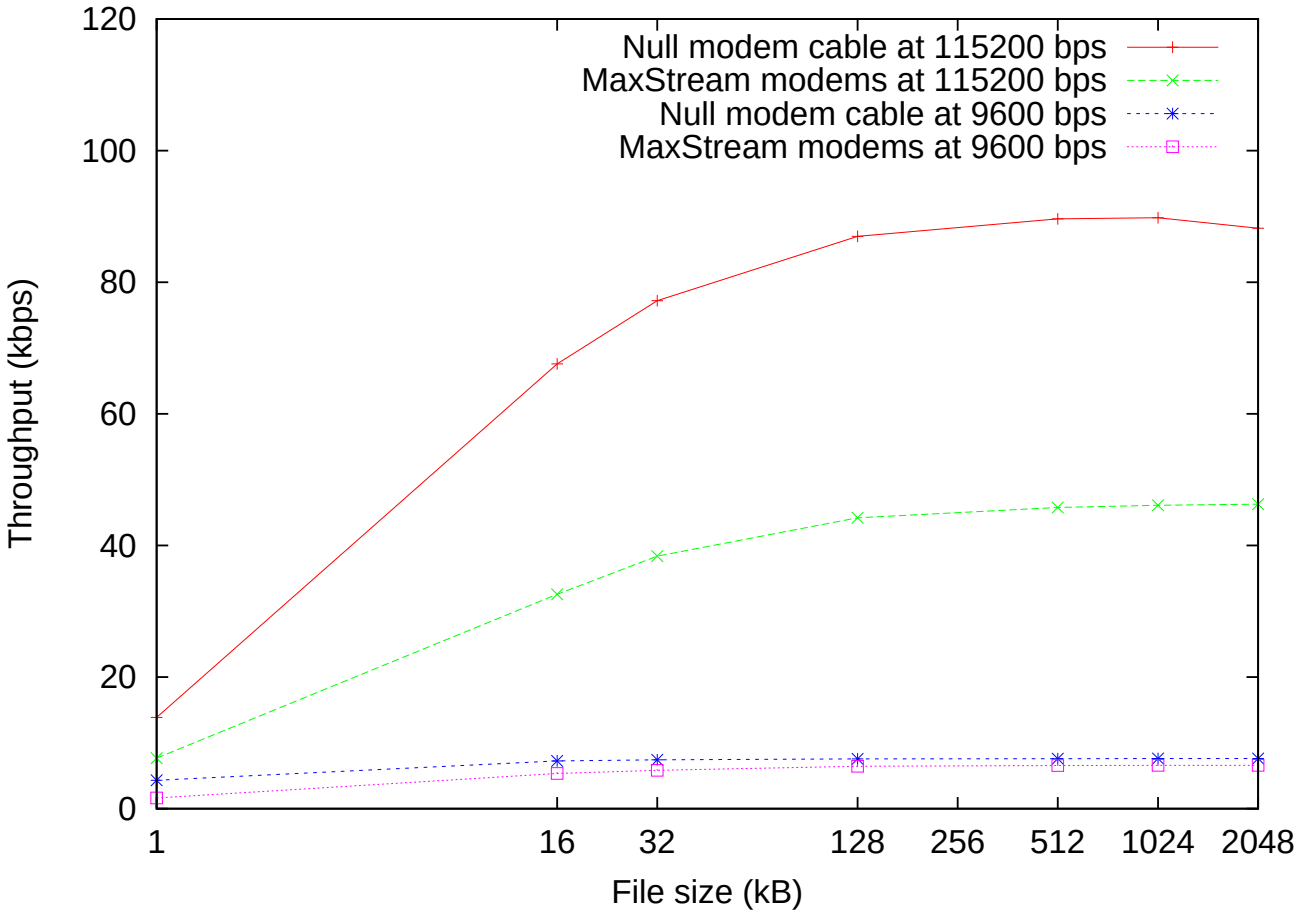
- *Throughput measurements*:
  - Motivation: bulk data transfer using a reliable protocol
  - Measurement methods:
    - Kermit file transfer
    - TCP throughput measured using *netperf*
- *Latency and jitter measurements*:
  - Motivation: command and control messaging
  - Two scenarios:
    - Single character round-trip
    - Round trip of a 64-byte message
  - Jitter measures:
    - *Average jitter*: average of the absolute values of differences between message latency and the average latency
    - *Max-min jitter*: difference b/w max. and min. latencies

# Throughput Experiments: FreeWave Modems




Throughput of a kermit file transfer

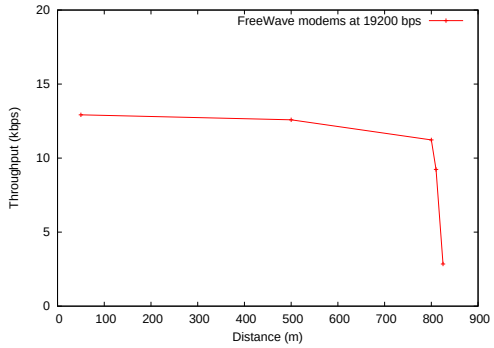
# Throughput Experiments: MaxStream Modems




Throughput of a kermit file transfer

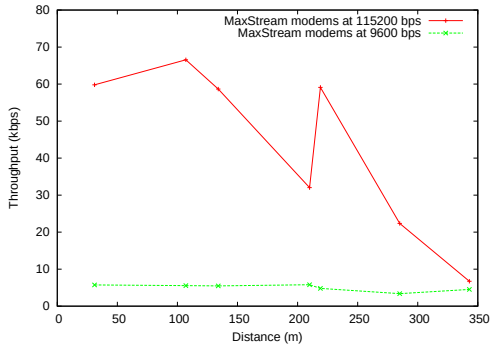
# Distance Experiments

Tests were carried out on the UNH campus, one modem on the third floor of a campus building, the other in a car. For most test locations, there were trees and overhead wires in the line of sight but no buildings.



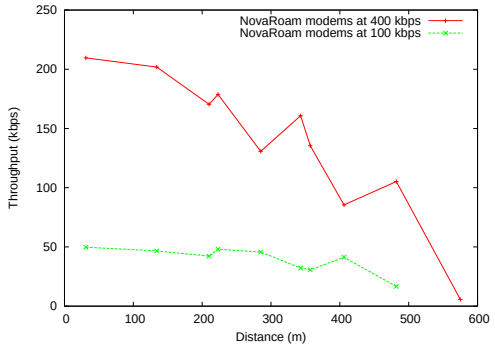

*FreeWave*

800+ m




*MaxStream*

300+ m




*NovaRoam*

500–600 m

# Throughput and round-trip latency of NovaRoam modems – measured using netperf

| Experiment | RF Data Rate (kbps) | Router mode | Bridge mode |
|---|---|---|---|
| TCP throughput (kbps) | 100 | 48.3 | 37.2 |
| | 400 | 203.5 | 186.4 |
| TCP 1-byte request-response (ms) | 100 | 54.4 | 52.9 |
| | 400 | 14.5 | 12.3 |
| TCP 64-byte request response (ms) | 100 | 70.0 | 63.2 |
| | 400 | 19.0 | 17.7 |

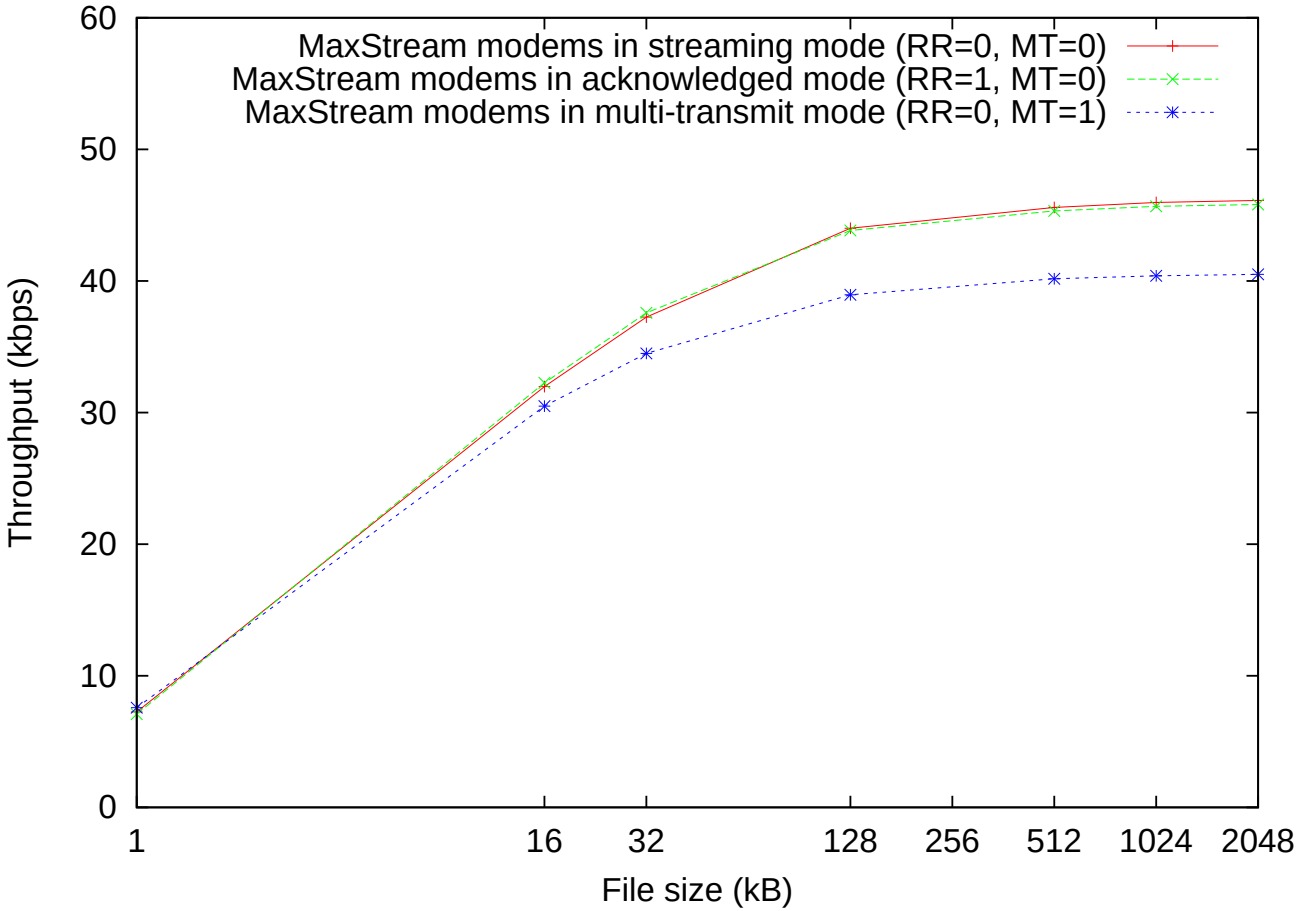
# Latency and jitter for 1-byte request-response experiments

| Modem Type | Rate (bps) | Latency (ms) | Jitter (ms) Average | Jitter (ms) Min/Max |
|---|---|---|---|---|
| Loopback connector | 9600 | 5.85 | 0.08 | 6.51 |
| | 19200 | 2.95 | 0.12 | 1.21 |
| | 115200 | 0.90 | 0.04 | 1.29 |
| Null modem cable and a character-loopback client | 9600 | 15.70 | 0.48 | 12.01 |
| | 19200 | 7.97 | 0.31 | 14.00 |
| | 115200 | 4.01 | 0.59 | 44.73 |
| *FreeWave* w/o repeater | 19200 | 20.95 | 2.33 | 21.06 |
| with a repeater (2 hops) | 19200 | 88.40 | 14.41 | 80.15 |
| *MaxStream* | 9600 | 46.17 | 3.16 | 33.01 |
| | 115200 | 45.09 | 4.64 | 17.89 |

# Latency and jitter for 64-byte request-response experiments

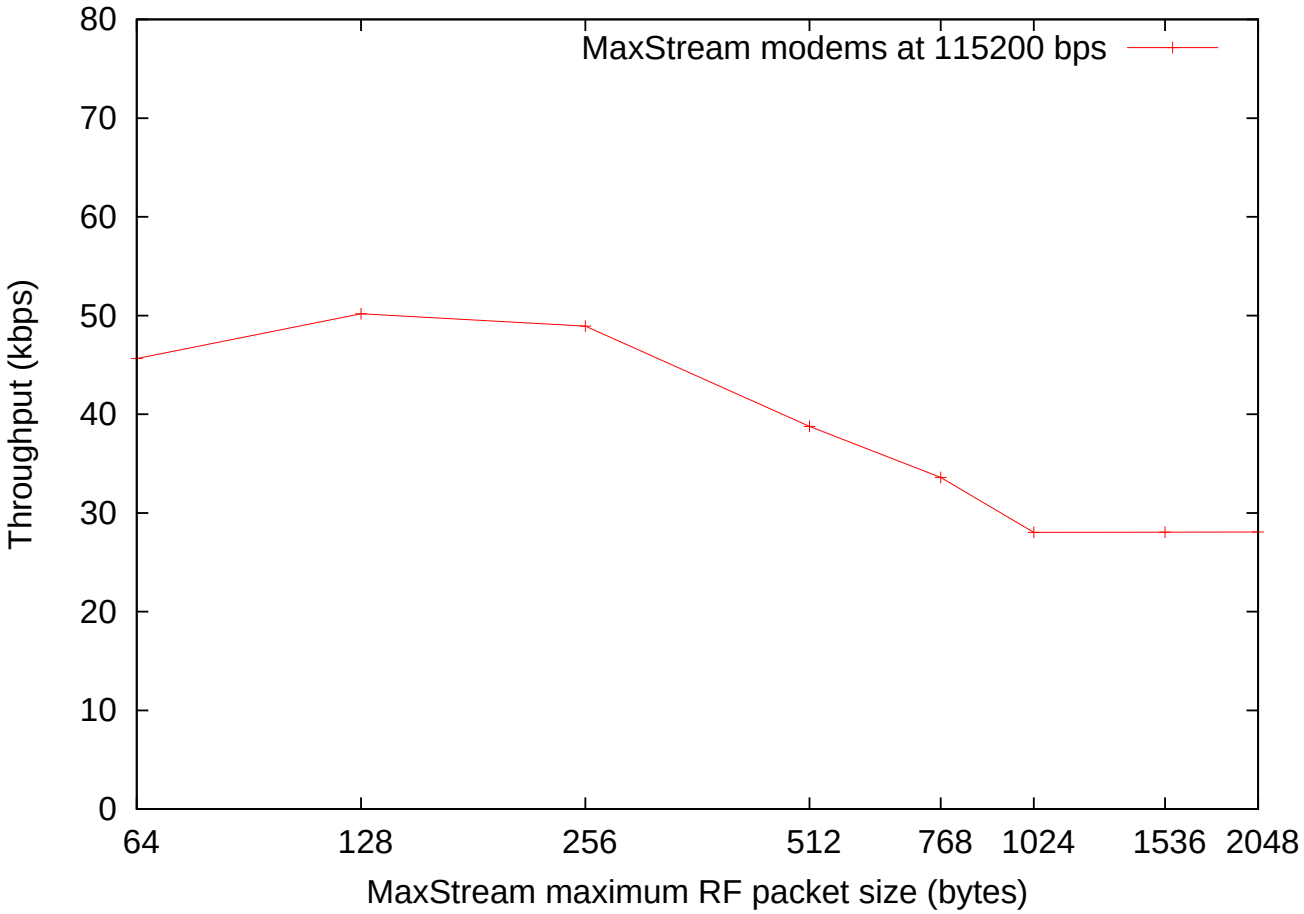
| Modem Type | Rate (bps) | Latency (ms) | Jitter (ms) Average | Jitter (ms) Min/Max |
|---|---|---|---|---|
| Null modem cable and a message-loopback client | 9600 | 135.76 | 0.13 | 2.01 |
| | 115200 | 14.24 | 1.90 | 6.08 |
| *MaxStream* | 9600 | 319.98 | 1.33 | 32.01 |
| | 115200 | 80.46 | 1.33 | 14.26 |

# MaxStream Transmission Modes




MaxStream modems under different modes (RF rate 115200 bps)

# MaxStream Packet Size Experiments




Kermit file transfer throughput vs. maximum RF packet size (kermit packet size fixed at 1024 bytes, RF rate 115200 bps)

# Conclusions and Future Work

- Maximum achievable payload throughput is only a fraction of the RF data rate.
- There is significant increase in latency when compare to wired connections, likely caused by packetization overhead.
- Similarly, there is a significant increase in jitter.
- Support for automated control and management of the modems can be improved.
- Multi-hop transmission capabilities of RF modems are still immature.

# Questions?