# Delay Tolerant Network Routing

**Sathya Narayanan, Ph.D.**

**Computer Science and Information Technology Program**

**California State University, Monterey Bay**

This work is supported by the Naval Postgraduate School – Military Wireless Communications Research Group

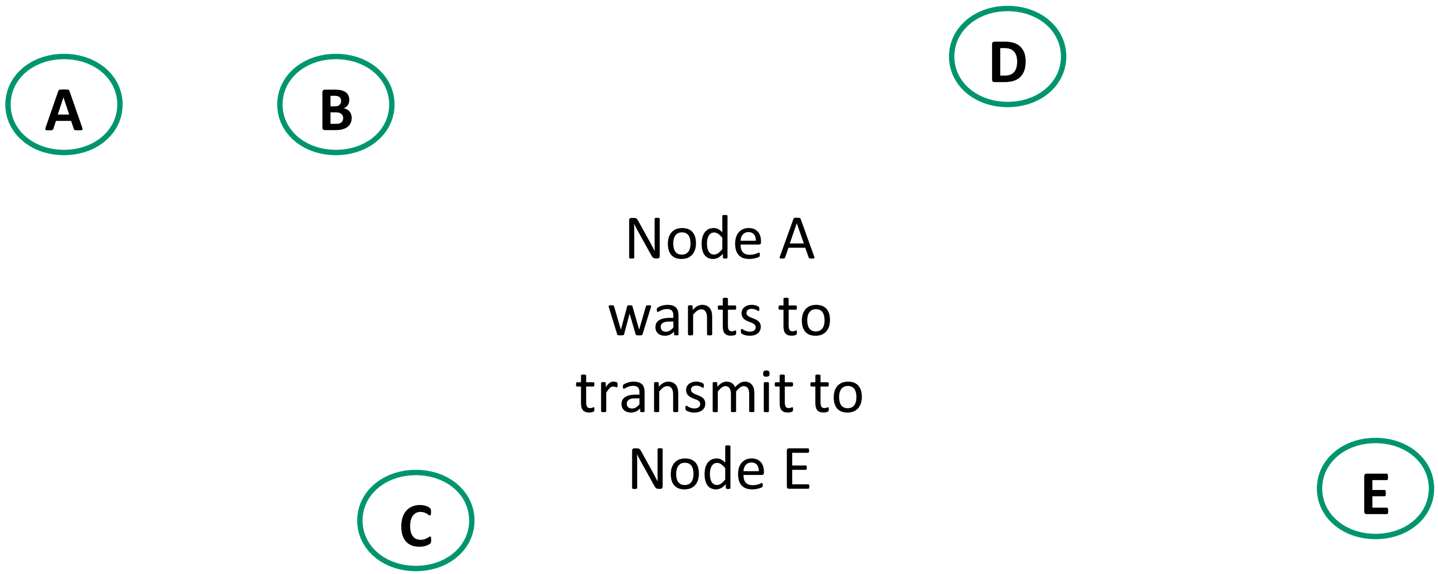
# Overview of Talk

- **Background**
- **Research Objective**
  - Performance analysis
  - Message Prioritization
- **Simulation Study**
  - Results
- **Future Plans**

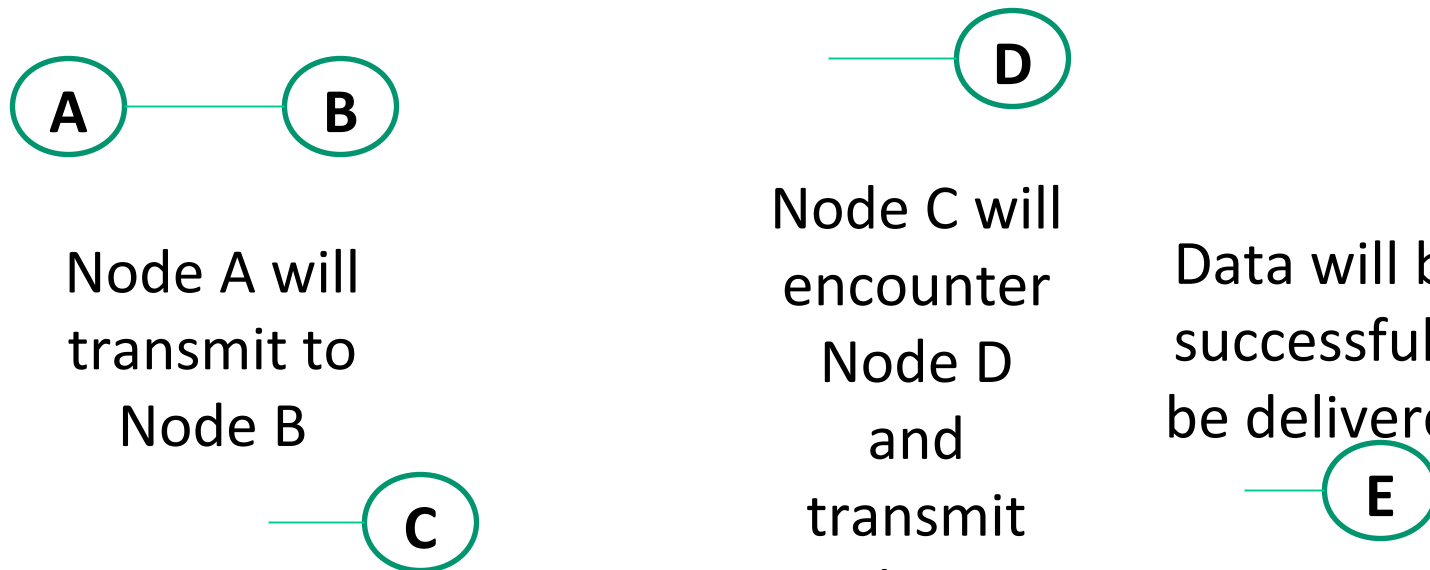
# Delay Tolerant Network Routing

- **Traditional networks**
  - Route from source to destination exists when the message leaves the source
- **Delay tolerant networks**
  - No pre-existing route
  - Message is forwarded as nodes encounter each other
    - Message traverses the route over time as the nodes move around

# Delay Tolerant Network



# Delay Tolerant Network




Node A will transmit to Node B

Node B will encounter Node C and transmit data

Node C will encounter Node D and transmit data

Data will be successfully be delivered

# Routing Protocols

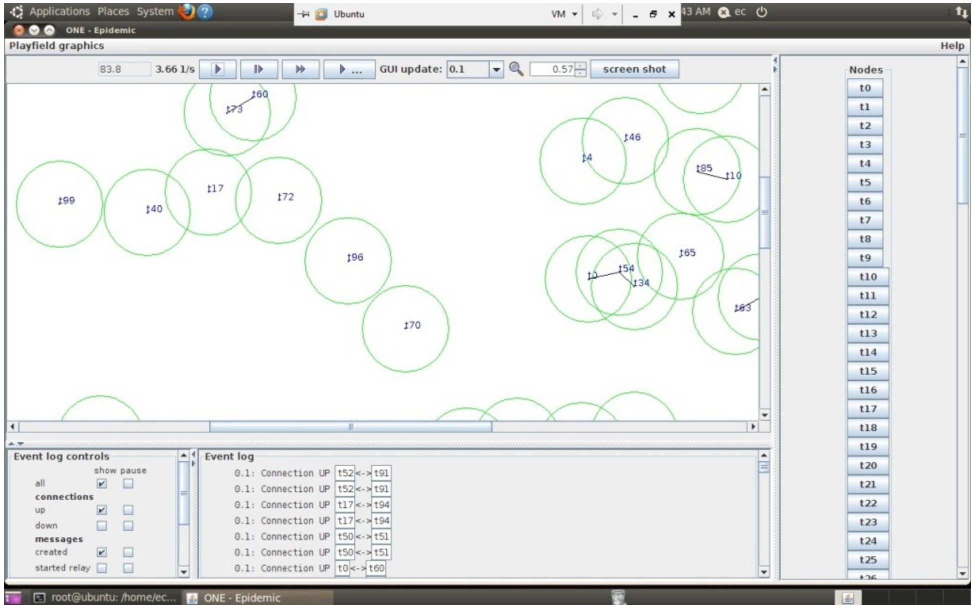
- **This research focuses on two routing protocols**
- **Epidemic Routing**
  - Forward message to every node encountered
  - Message spreads like that of a disease in a population
- **ProPHET**
  - Probabilistic Routing Protocol using History of Encounters and Transitivity
  - Use past encounters to predict future best route
  - Provides a framework allowing for different forwarding decision algorithms

# Research Objective

- **Message Prioritization**
  - Use the insights gained from analysis to develop message prioritization algorithms for DTN routing
- **Performance analysis**
  - Develop analytical and simulation models to study three related performance parameters
    - Duplicate messages in the network at the time of delivery
    - End to end latency of message delivery
    - Probability of message delivery

# Current Status

- Developed four types of ProPHET forwarding decision algorithms
- Developed a simple probabilistic extension to Epidemic (q – Epidemic)
- Extensive simulation analysis of Epidemic vs ProPHET routing using ONE (Opportunistic Network Environment Simulation tool)



# Results

- **A lot of data collected**
- **Some insights:**
  - q = 0.5 Epidemic has similar performance as ProPHET without all the complexity when Random Waypoint Mobility is used
  - Aggressive algorithms have low latency at low message generation rates
  - We haven’t seen any consistent performance improvement by ProPHET when there is any randomness in the mobility pattern (More simulations are being run as we speak)

# Results

- **Insights continued:**
  - Variables that impact the latency are:
    - Message generation rate
    - Queue length
    - Number of nodes
    - Aggressive vs non aggressive algorithms

# Sample Results

| 10 Nodes | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Epidemic | | | Epidemic | | | Prophet | | | Prophet | | |
| | | | q0.5 | | | q1.0 | | | Type2 | | | Type4 | | |
| | Src | Dst | Duplicates | Latency | Probability | Duplicates | Latency | Probability | Duplicates | Latency | Probability | Duplicates | Latency | Probability |
| Low | 1 | 1 | 4.6 | 5854 | 0.9 | 8.2 | 2321 | 1 | 1.8 | 7164 | 0.4 | 3.2 | 8795 | 0.5 |
| | 1 | 2 | 4 | 5471 | 0.9 | 8.2 | 1919 | 1 | 2.1 | 7114 | 0.7 | 4.2 | 6232 | 0.9 |
| | 2 | 2 | 3.7 | 3601 | 1 | 7.6 | 1546 | 1 | 2.5 | 4283 | 1 | 3.4 | 3535 | 1 |
| Med | 1 | 1 | 3.4 | 9043 | 0.5 | 4.6 | 6951 | 0.9 | 2.19 | 8783 | 0.3 | 2.6 | 8837 | 0.4 |
| | 1 | 2 | 2.9 | 8522 | 0.7 | 4.4 | 6464 | 0.9 | 2 | 8321 | 0.6 | 3.5 | 7441 | 0.8 |
| | 2 | 2 | 2.7 | 6450 | 1 | 3.8 | 4273 | 1 | 2.5 | 6765 | 0.8 | 3.2 | 4975 | 0.9 |
| High | 1 | 1 | 3.3 | 8519 | 0.4 | 4.5 | 8721 | 0.6 | 2.13 | 10417 | 0.2 | 3.6 | 10579 | 0.2 |
| | 1 | 2 | 3 | 9007 | 0.5 | 4.3 | 8805 | 0.7 | 1.75 | 7737 | 0.4 | 2.8 | 8165 | 0.4 |
| | 2 | 2 | 2.7 | 9112 | 0.6 | 3.7 | 8236 | 0.8 | 2 | 7259 | 0.8 | 3 | 6764 | 0.8 |

| 40 Nodes | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Epidemic | | | Epidemic | | | Prophet | | | Prophet | | |
| | | | q0.5 | | | q1.0 | | | Type2 | | | Type4 | | |
| | Src | Dst | Duplicates | Latency | Probability | Duplicates | Latency | Probability | Duplicates | Latency | Probability | Duplicates | Latency | Probability |
| Low | 1 | 1 | 14.5 | 1389 | 1 | 22.5 | 724 | 1 | 3.2 | 6669 | 0.6 | 9.3 | 3277 | 1 |
| | 1 | 2 | 13.6 | 1368 | 1 | 22.7 | 744 | 1 | 3 | 5537 | 0.9 | 10.3 | 1665 | 1 |
| | 2 | 2 | 13.2 | 1097 | 1 | 20.3 | 663 | 1 | 3.4 | 2633 | 1 | 10.7 | 1258 | 1 |
| Med | 1 | 1 | 14 | 2218 | 1 | 21.9 | 793 | 1 | 2.7 | 7585 | 0.6 | 8.5 | 5057 | 0.8 |
| | 1 | 2 | 12.3 | 1681 | 1 | 21 | 800 | 1 | 2.7 | 6883 | 0.8 | 8.8 | 3078 | 1 |
| | 2 | 2 | 11 | 1550 | 1 | 20 | 714 | 1 | 3.1 | 3599 | 1 | 9.8 | 1572 | 1 |
| High | 1 | 1 | 10.3 | 5689 | 1 | 23.1 | 1759 | 1 | 3.2 | 8447 | 0.3 | 10.1 | 7506 | 0.5 |
| | 1 | 2 | 9.7 | 5862 | 0.9 | 19.5 | 1626 | 1 | 2.8 | 8693 | 0.6 | 8.1 | 5881 | 0.9 |
| | 2 | 2 | 7.9 | 3387 | 1 | 21.7 | 1068 | 1 | 2.7 | 6802 | 0.9 | 9.1 | 3982 | 1 |

# Conclusion

- **Throttling Epidemic behavior using a q value seems to work well**
- **Mathematical analysis based on the input variables is needed**
  - Work in progress
- **Few levers available to affect message prioritization at routing**
  - q value for Epidemic
  - Limit on the number of hops
  - Prioritization within queues

# Two Related Recent Projects

- **Experimentation with Simple Message Prioritization Extensions to ProPHET**
  - NPS Master Thesis (March 2011, LT Rapin, USN)

- **Secure Distributed Storage for Mobile Devices**
  - NPS Master thesis (March 2011, LT Huchton, USN)
  - Upcoming MILCOM paper

# Experimentation with ProPHET Message Prioritization

- **Simple extensions (with two traffic priority classes) can increase the performance of high priority messages significantly**
  - Higher message delivery rate
  - Lower message latency
- **Urgent need of stable software prototypes to advance DTN research beyond theory and simulations**
  - The current IRTF DTN2 reference implementation is of very low quality

# A Secure Distributed File System for Mobile Devices

- **Resistant to total device compromise**
  - Up to a customizable number (*k*) of device captures
  - No need for specialized tamper-resistant hardware
  - Addressing limitation of “Remote Kill”
- **Group secret sharing also supports data resiliency**
  - Different collection of *k* devices can recover data
- **Prototype on Android 2.2 Smart Phones**
  - write() and read() throughput performance:  up to 15 Mbps

# Backup Slides

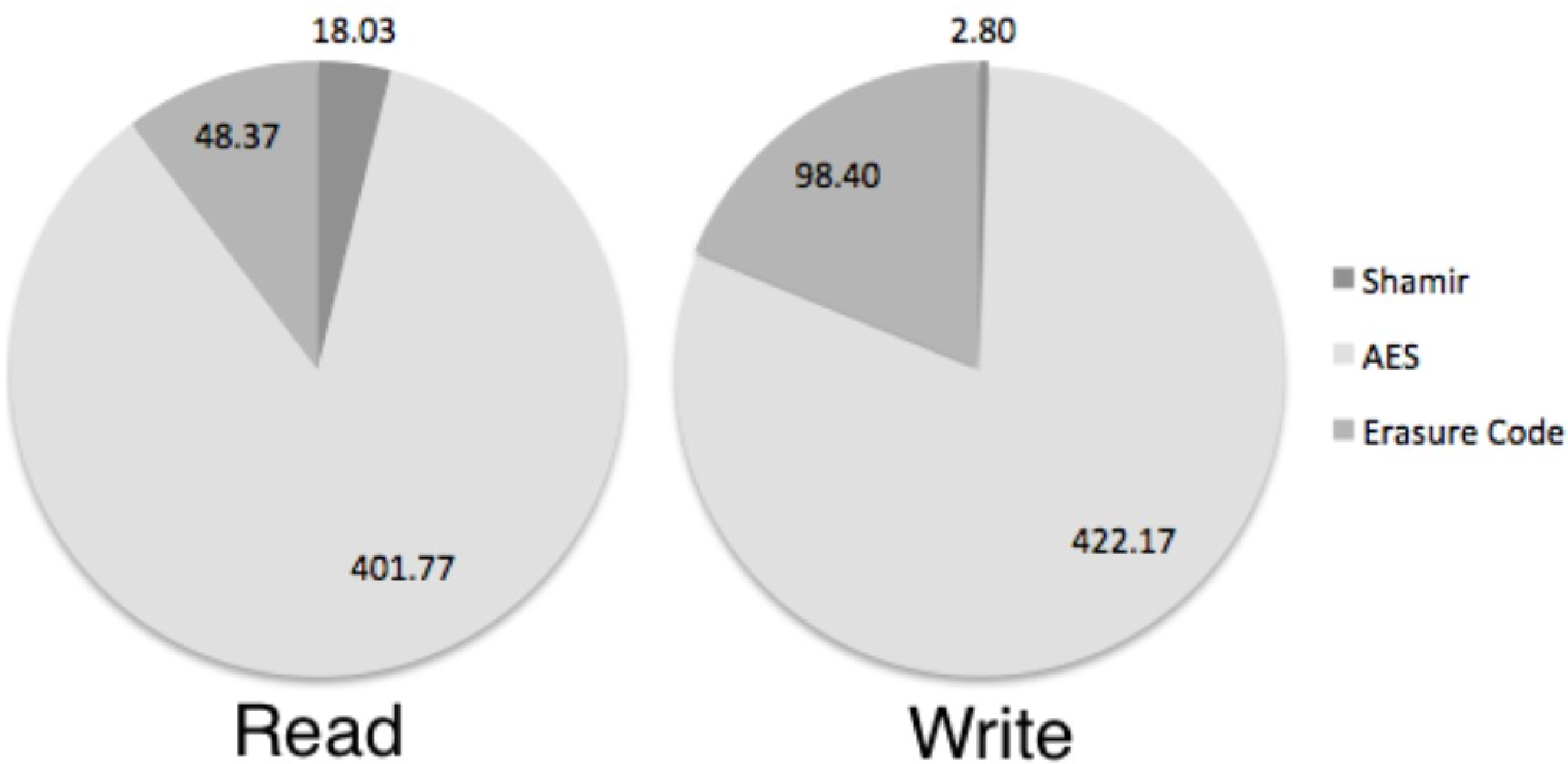
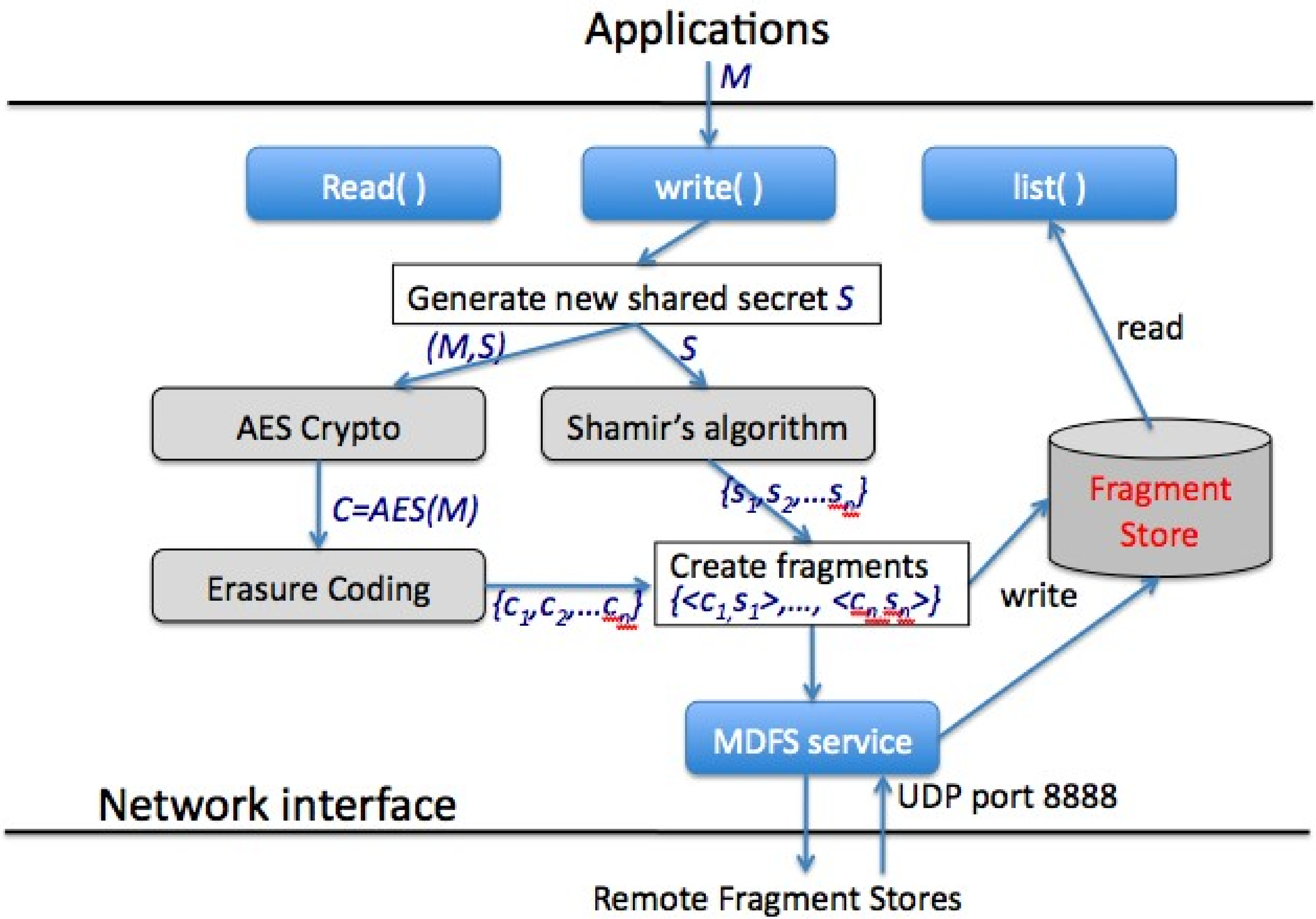



Fig. 4. Average Executive Times (ms) for 1MB file


Applications
M
Read( )
write( )
list( )
Generate new shared secret S
(M,S)
S
read
AES Crypto
Shamir's algorithm
C=AES(M)
{s1,s2,...sn}
Fragment Store
Erasure Coding
Create fragments
{<c1,s1>,..., <cn,sn>}
write
{c1,c2,...cn}
MDFS service
Network interface
UDP port 8888
Remote Fragment Stores