

6LoWPAN WG, IETF64, Vancouver

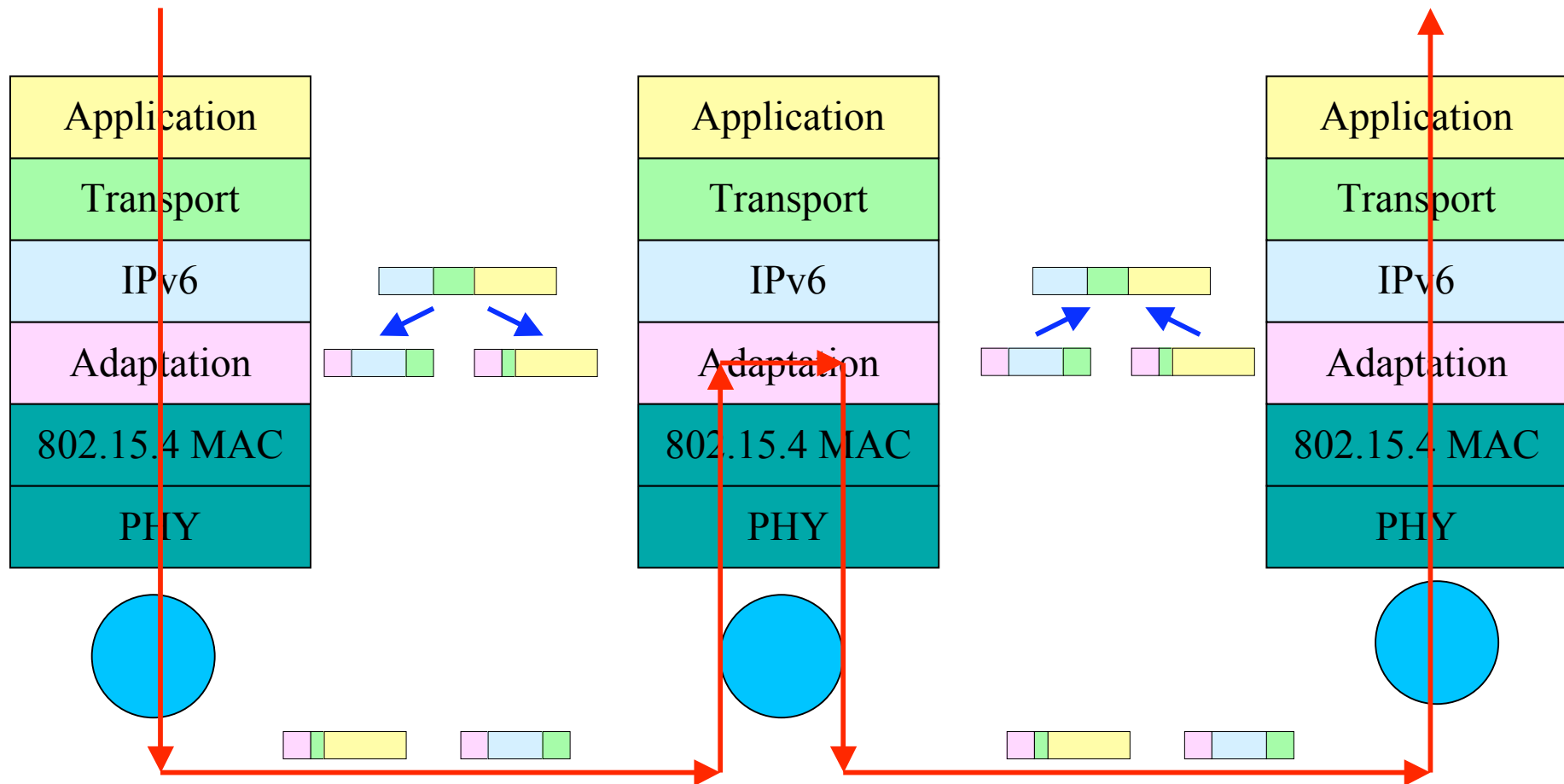
# Routing Protocol Comparison for 6LoWPAN

Ki-Hyung Kim (Ajou University) and  
S. Daniel Park (SAMSUNG Electronics)

# Contents

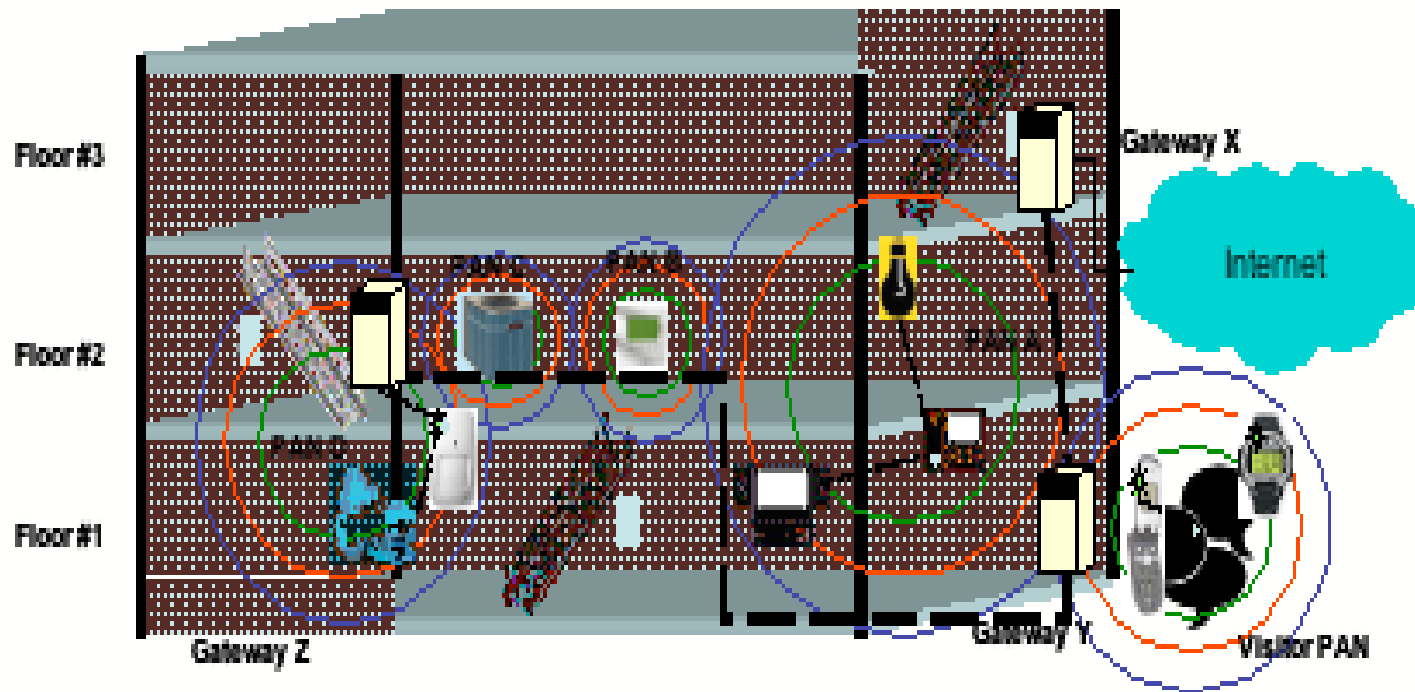
- 6LoWPAN Ad Hoc On-Demand Distance Vector Routing (**LOAD**)
  - draft-daniel-6lowpan-load-adhoc-routing-01.txt
- Route Error Reporting Schemes
- Dynamic MANET On-demand for 6LoWPAN (**DYMO-low**) Routing
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# Mesh Routing underneath to IPv6 Layer



# Inter-PAN Routing Protocol

- LOAD is an Interworking Routing Protocol for a PAN of Multiple PANs
- Furthermore, LOAD supports for Internet of PANS (i.e. Seamless All IP-based Wired Networks and Wireless PANs)



# 6LoWPAN Ad Hoc On-Demand Distance Vector Routing (LOAD)

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S. Daniel Park (SAMSUNG Electronics)  
G. Montenegro (Microsoft Corporation)  
S. Yoo (Ajou Univ)***

(draft-daniel-6lowpan-load-adhoc-routing-01.txt)

# Introduction

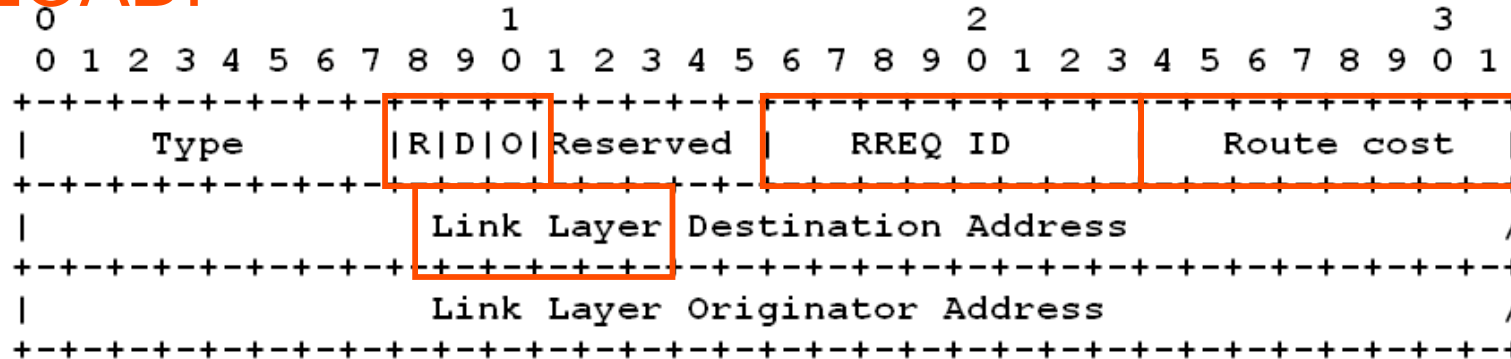
- 6LoWPAN Ad hoc Routing Protocol (LOAD) is a simplified on-demand routing protocol based on AODV[RFC3561] for 6LoWPAN
- Change-Log
  - This draft (01) is the merged version of
  - draft-daniel-6lowpan-load-adhoc-routing-00.txt
  - draft-montenegro-lowpan-aodv-00.txt

# Main Features of LOAD

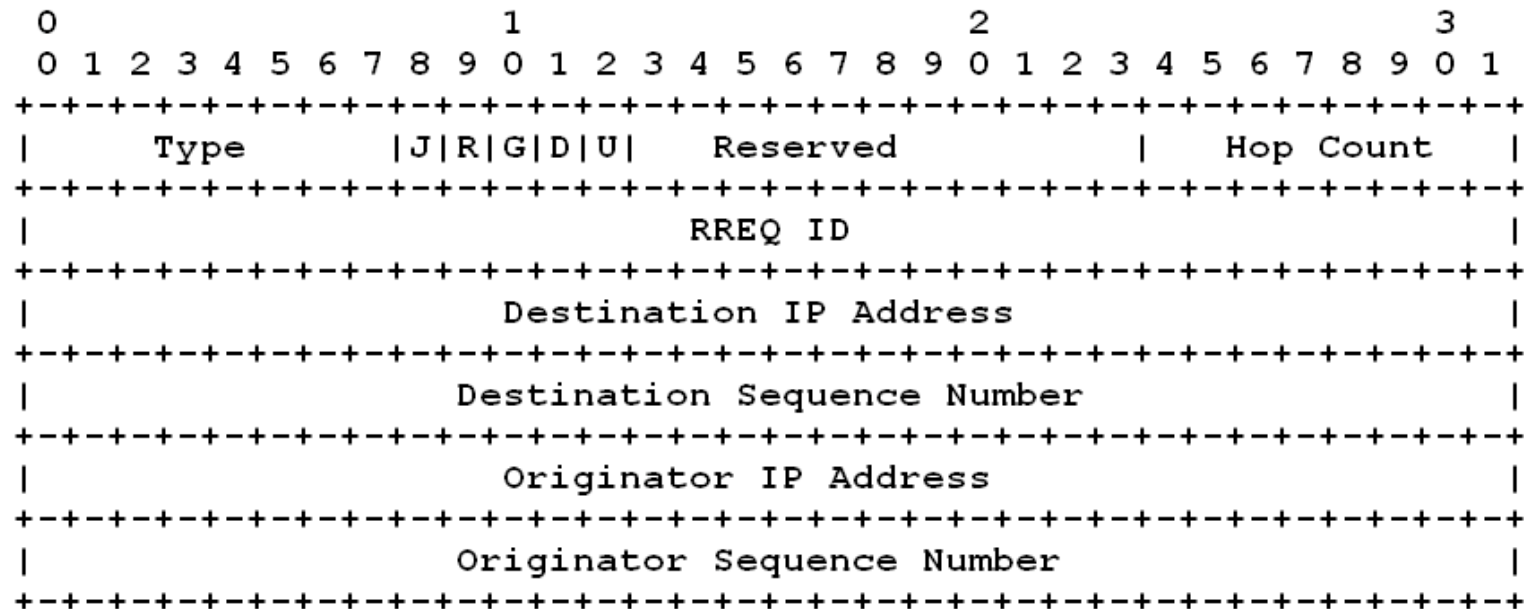
- Use EUI-64 or 16 bit addresses
- Use broadcast in the route discovery
- Do not use the destination sequence number
- Only destination Replies to RREQ by RREP
- Do not use the local repair
- Report back to the originator by RERR upon a link break
  - Do not maintain the precursorlist
  - Send RERR only to the originator of the data which caused the link break
- Use the route cost by utilizing the LQI of the 6LoWPAN PHY
  - Allow multiple schemes such as hop counts, aggregated LQI values, and minimum LQI value along a route
- Use the Acknowledged transmission option for keeping the connectivity of a route (Does not use HELLO)
- Maintains two tables: Route Request table, Routing table

# Route Request (RREQ) Message

## LOAD:



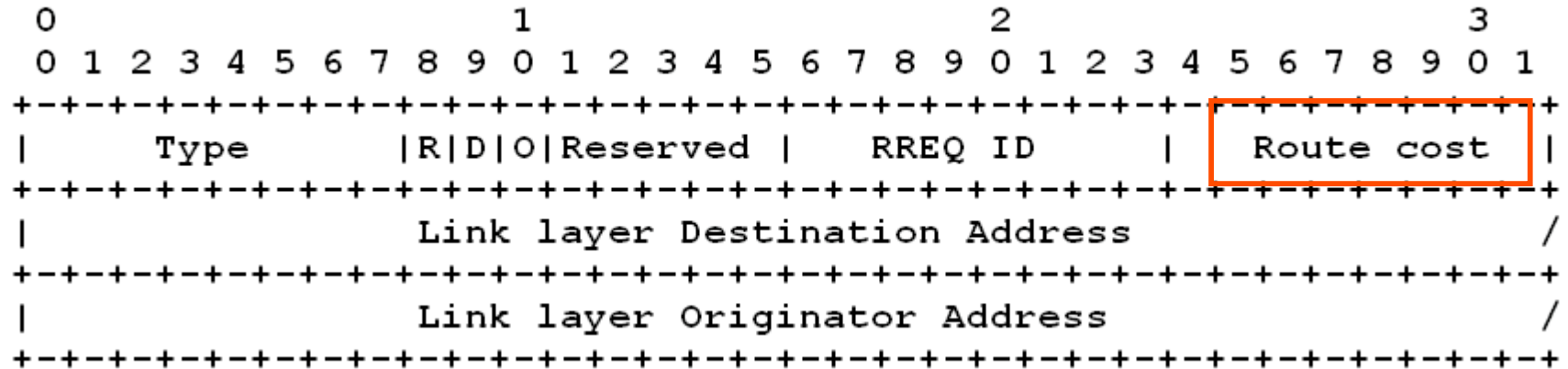
## AODV:



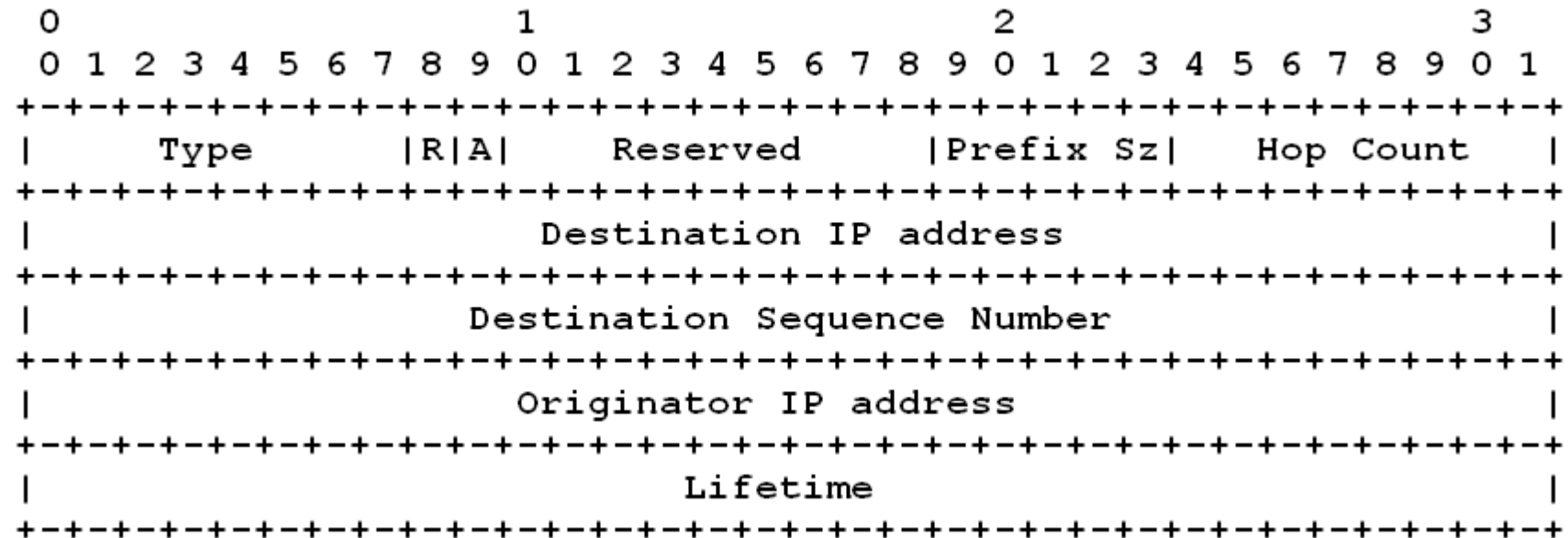


# Route Reply (RREP) Message

LOAD:

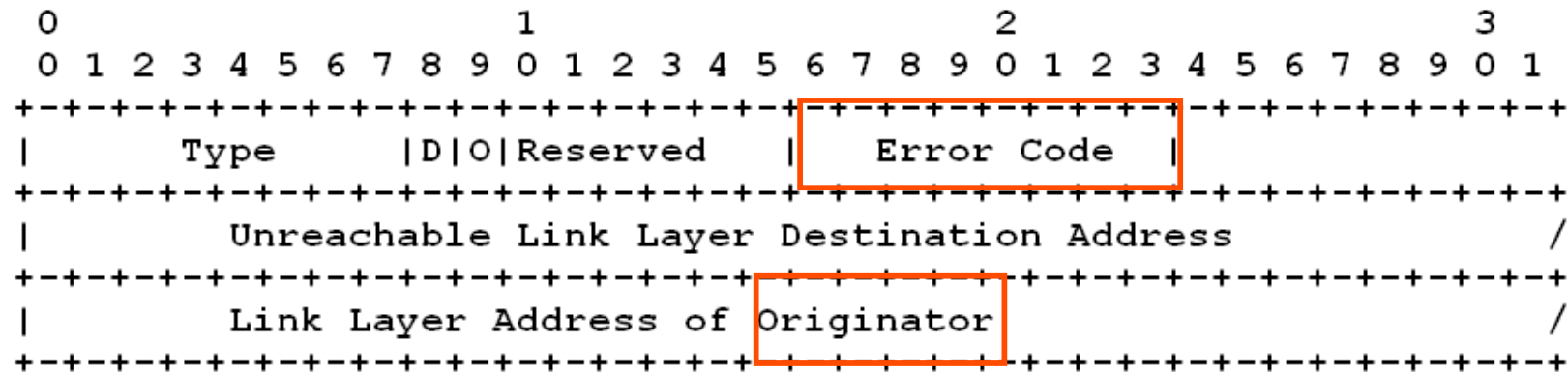


AODV:

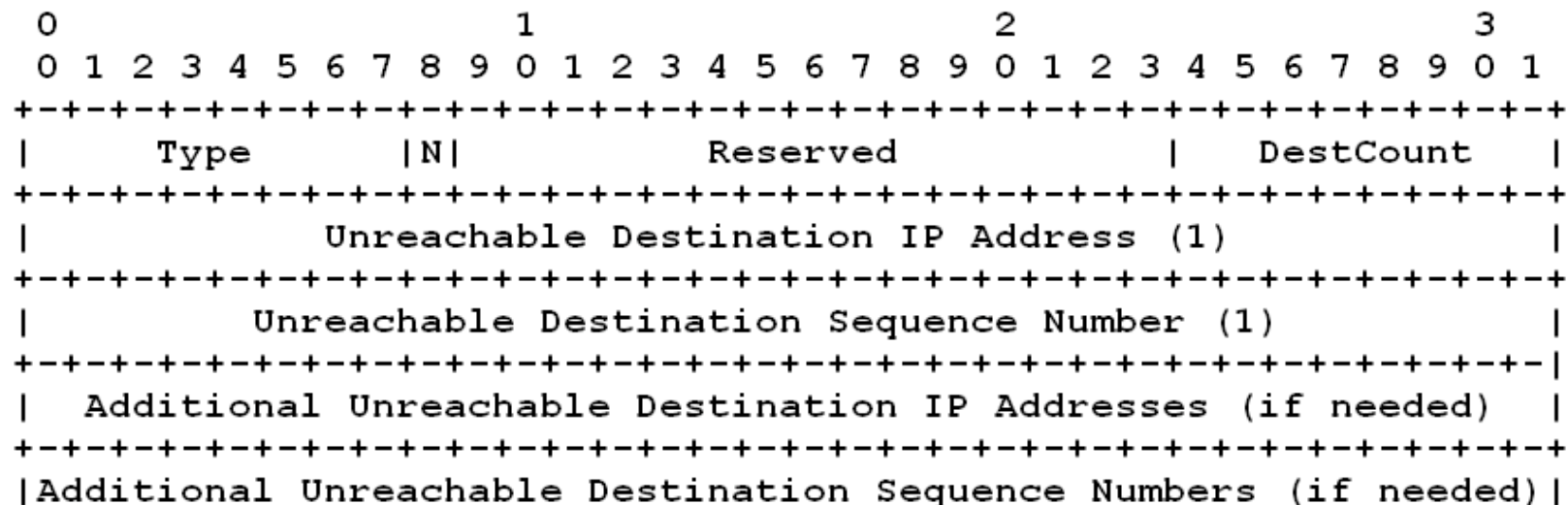


# Route Error (RERR) Message

## LOAD:



## AODV:



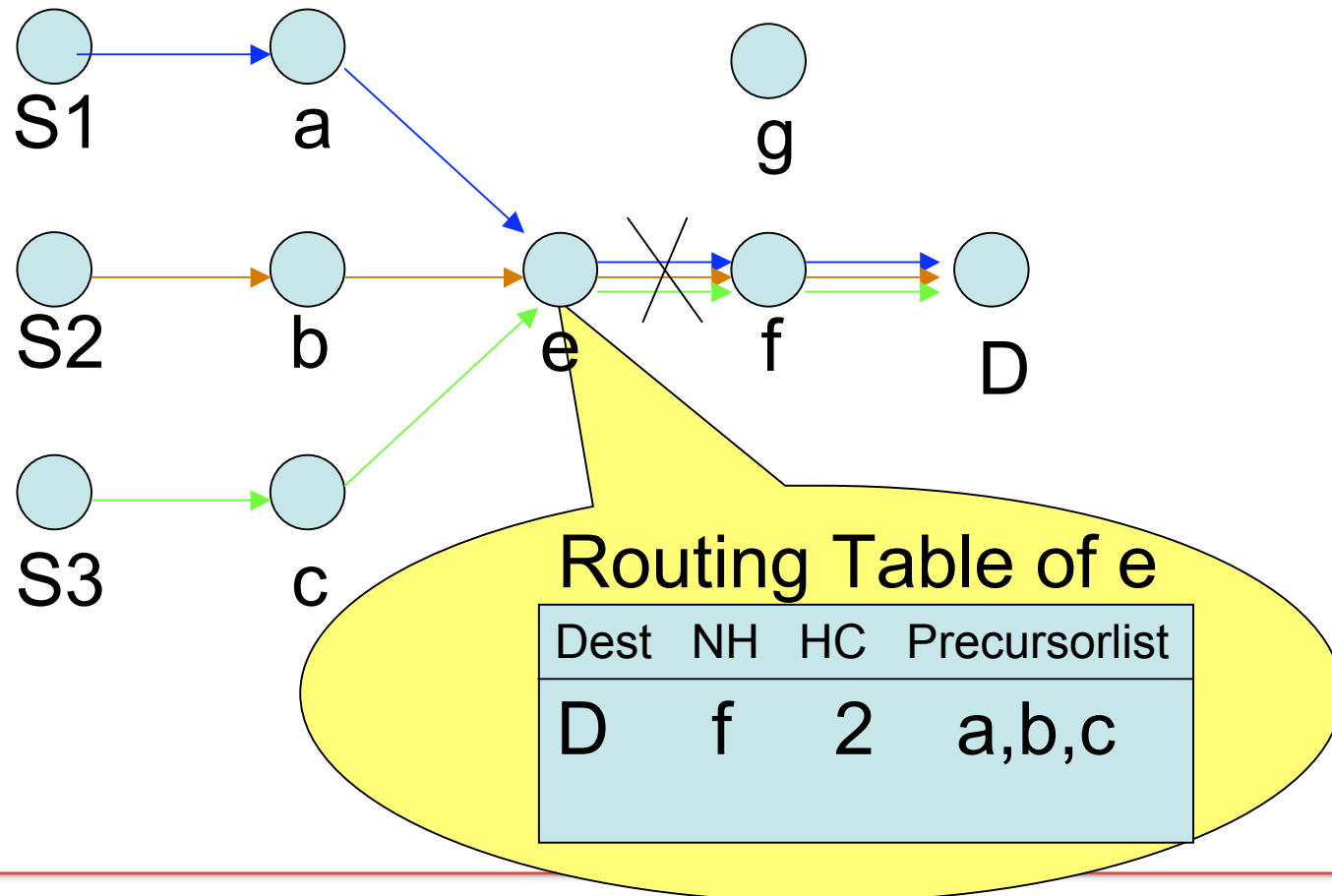
# Route Error Reporting Schemes

# RERR Back Propagation

- AODV
  - Utilize **Precursorlist** to reach the originators
- LOAD
  - Does not use **precursorlist** -- to reduce the overhead of RERR processing
  - Use the **originator address** of data packets
    - If the future revision of the format document allows the source address for multihop packets
    - Maintain symmetric forward and backward route on intermediate nodes
    - Does not allow local repair
  - Unicast **one-hop** back propagation when there is no way to know the route to the originator

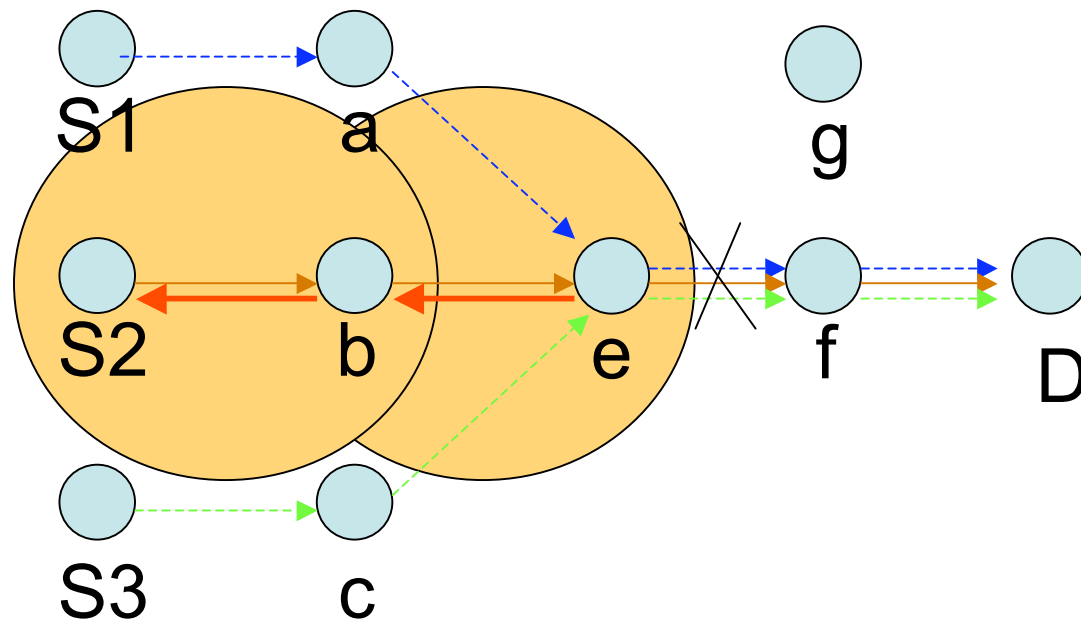
# Handling of Link Breaks in AODV

- Local Repair
- Precursorlist for RERR delivery



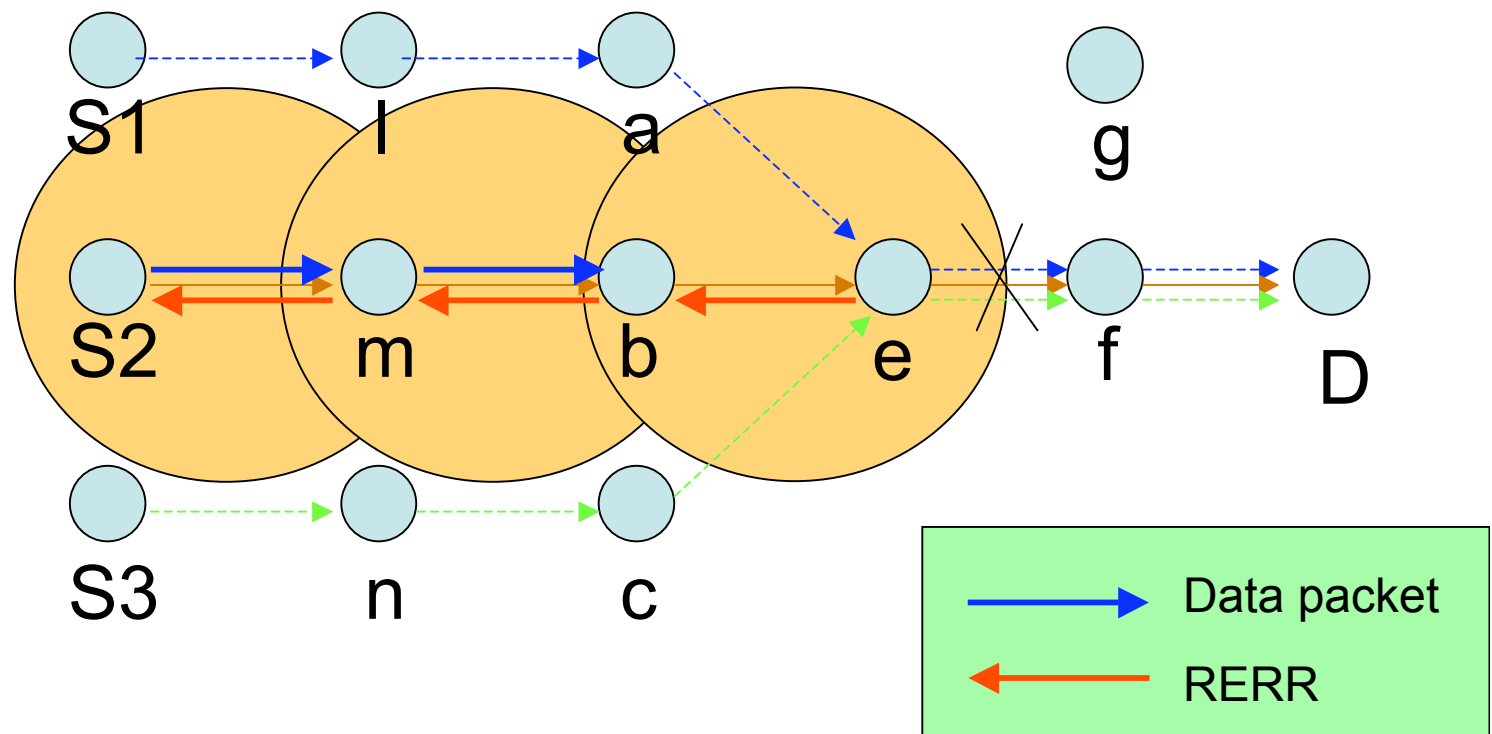
# Handling of Link Breaks in LOAD

- Solution 1)
  - Utilize the source address of data packet to send RERR to the originator (without precursor list)
  - Node on an active route keeps a reverse route entry for sending RERR to the originator



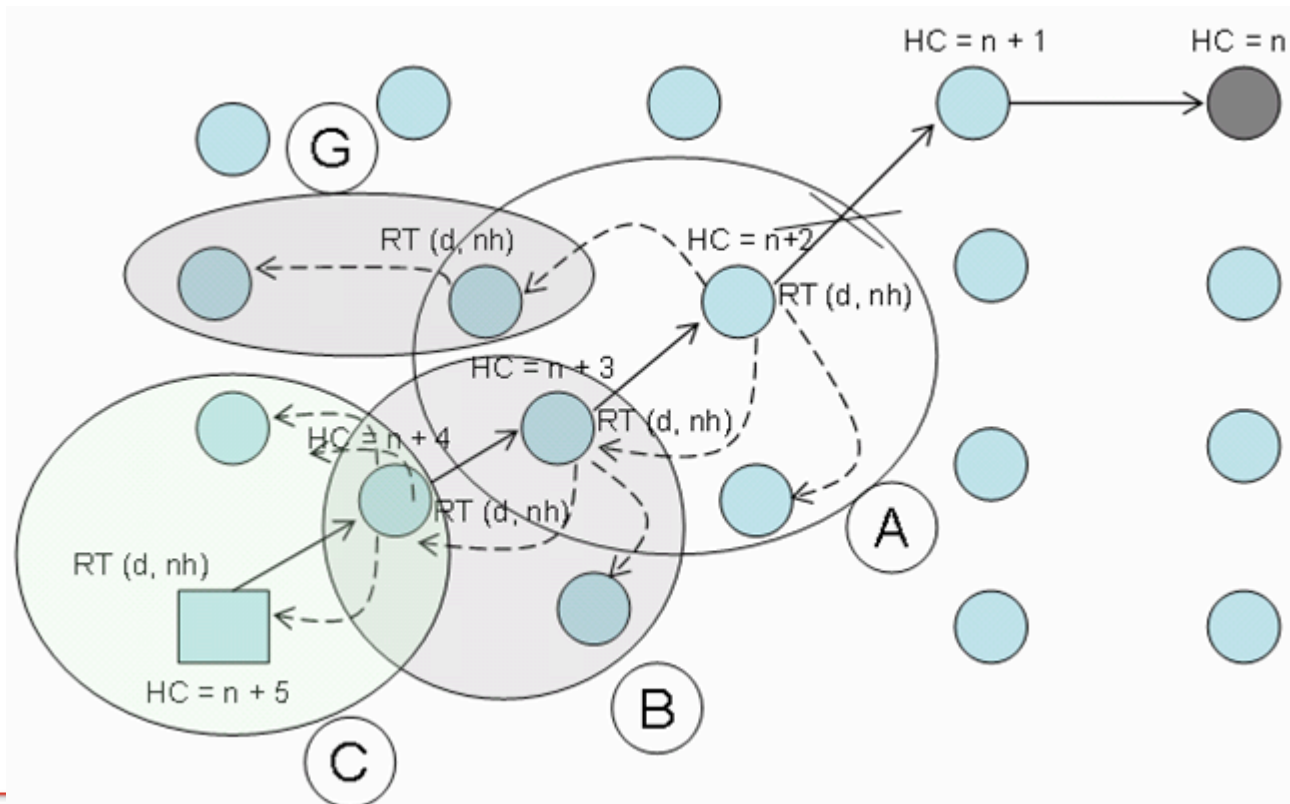
## Handling of Link Breaks in LOAD (2)

- Solution 2)
  - Unicast RERR back only to the previous hop node e



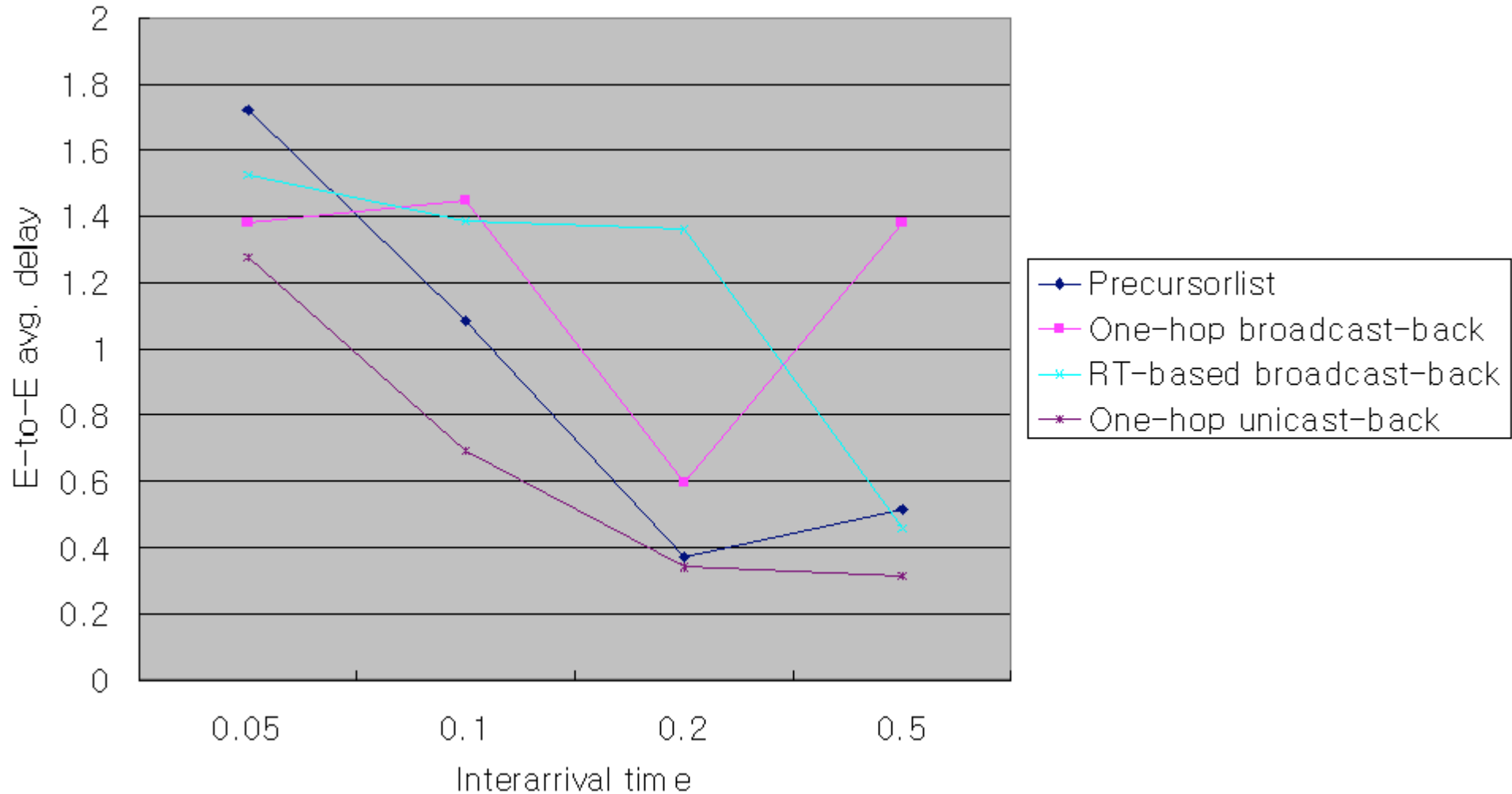
# Handling of Link Breaks in LOAD (3)

- Solution 3)
  - Broadcast RERR back by utilizing Routing table entries

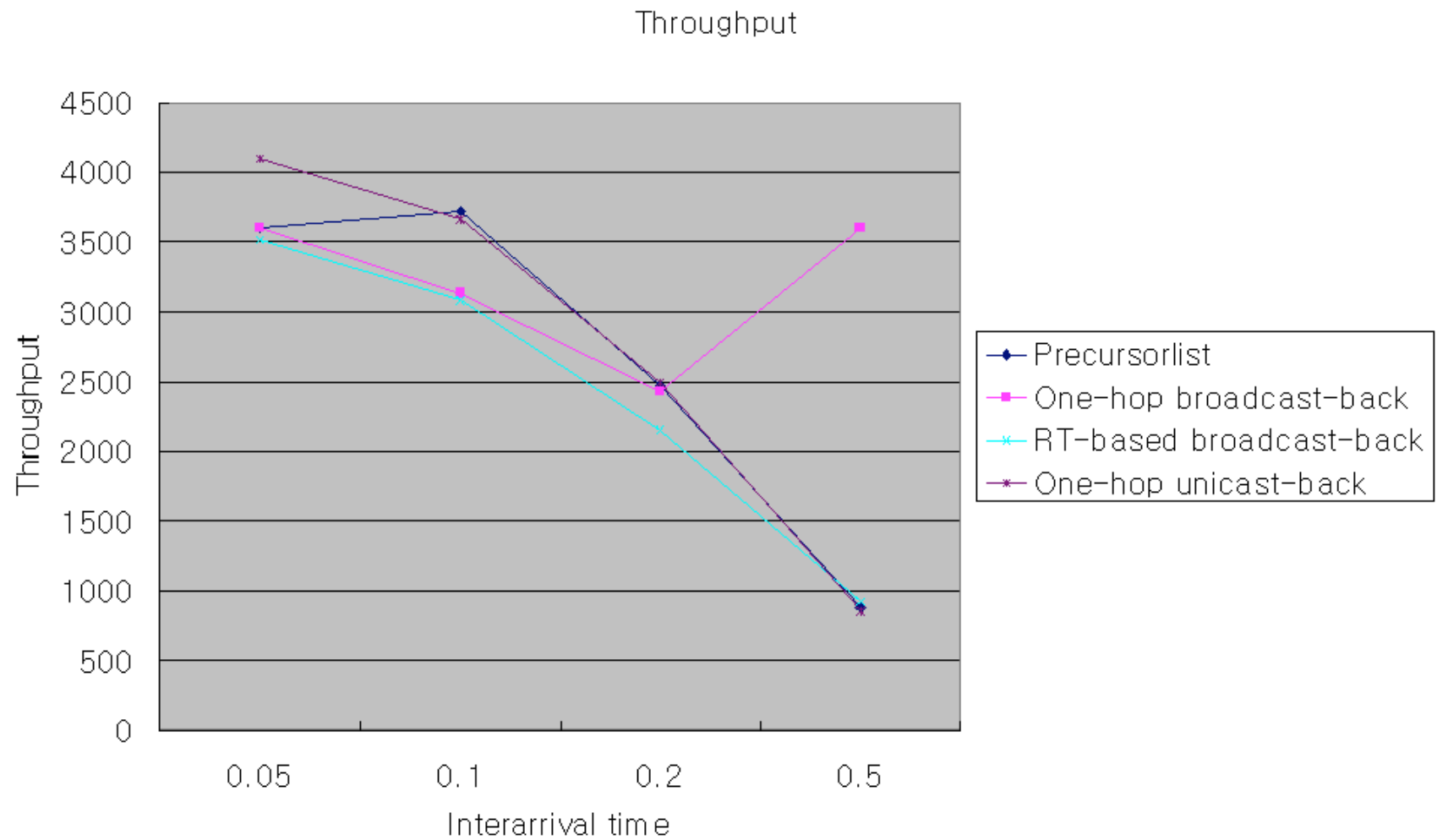




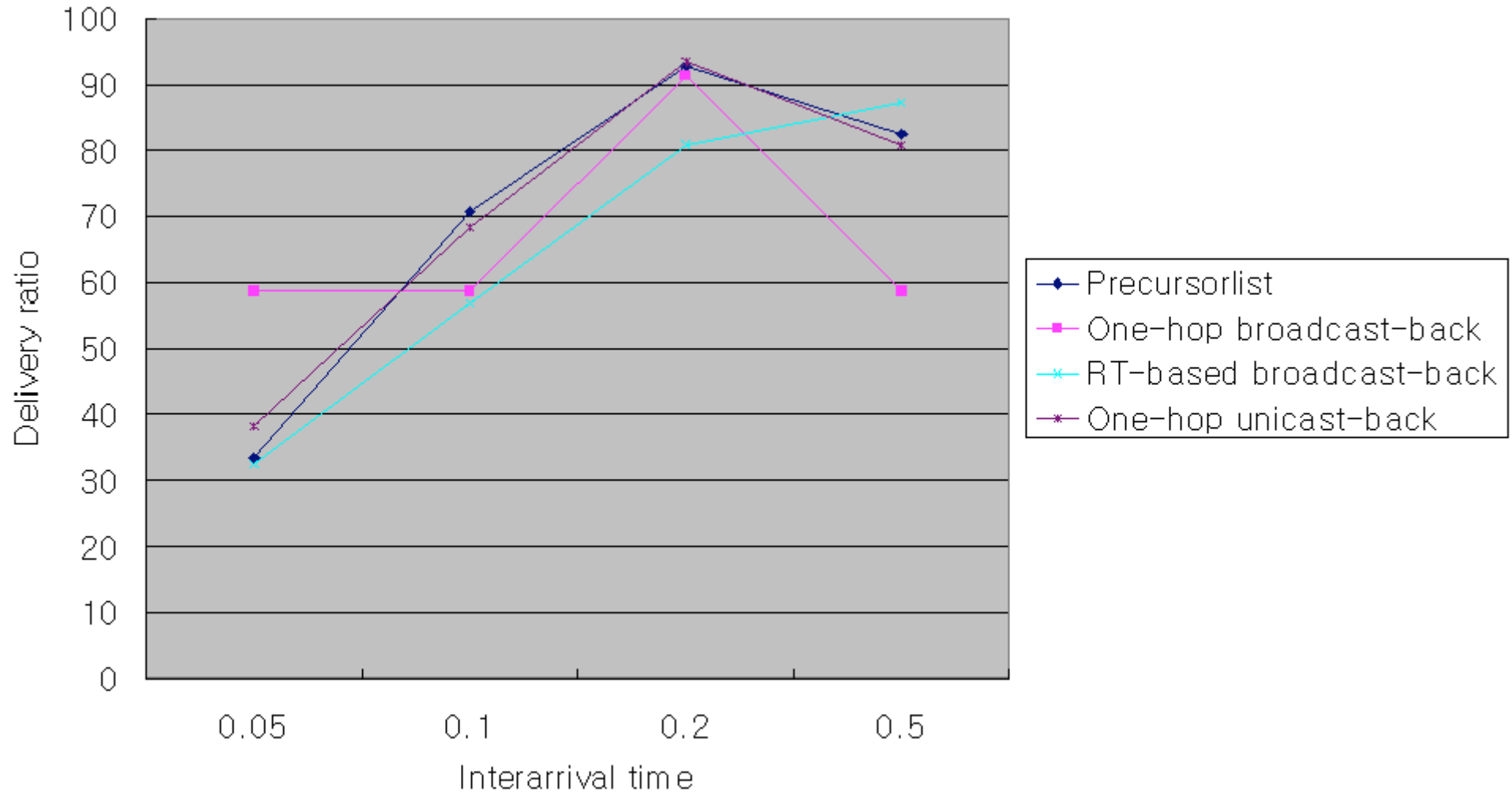
# End-to-End Delay



# Throughput



# Delivery Ratio



# Dynamic MANET On-demand for 6LoWPAN (DYMO-low) Routing

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**S. Daniel Park (SAMSUNG Electronics)**

**I. Chakeres (Boeing Phantom Works)**

**S. Yoo(Ajou University)**

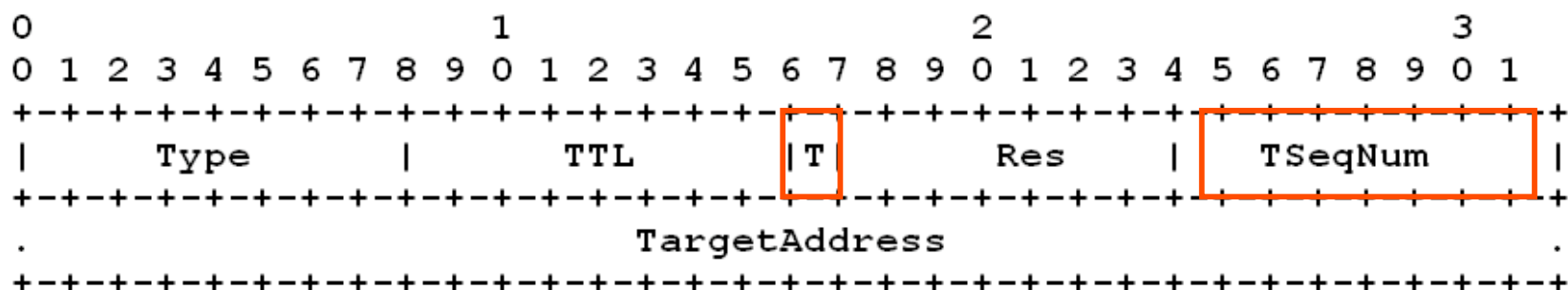
draft-montenegro-6lowpan-dymo-low-routing-00.txt

# Simplification from DYMO

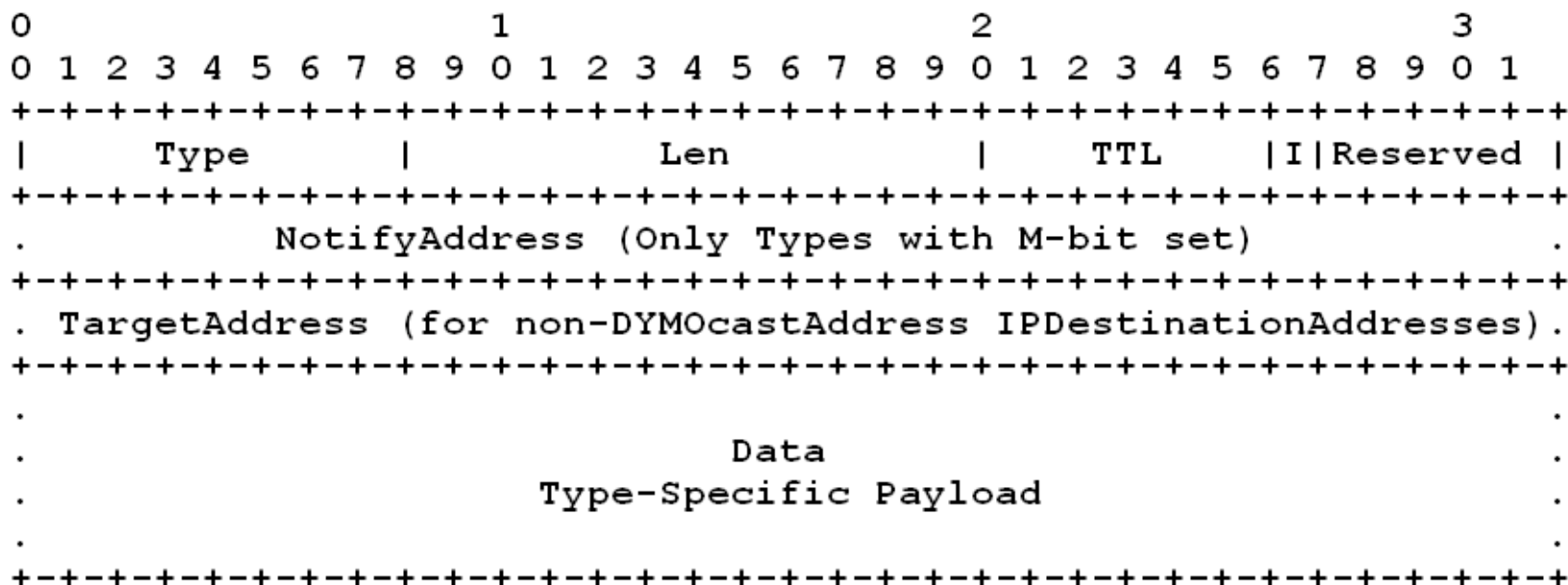
- Obviates UERR (Unsupported Element Error)
- DYMOcast is mapped as broadcast
- No path accumulation
  - Only one Routing Block (RBlock)
- Only the final destination responds
- Allow Multiple Routing Elements (RE)
  - Possibly reduce the number of control messages by aggregation
- Limit on the number of control message
- Inserted the Error Code field into RERR
- Utilize LQI for route cost calculation
- Do not use HELLO message and Sequence Number

# Generic Element Structure

## DYMO-low:

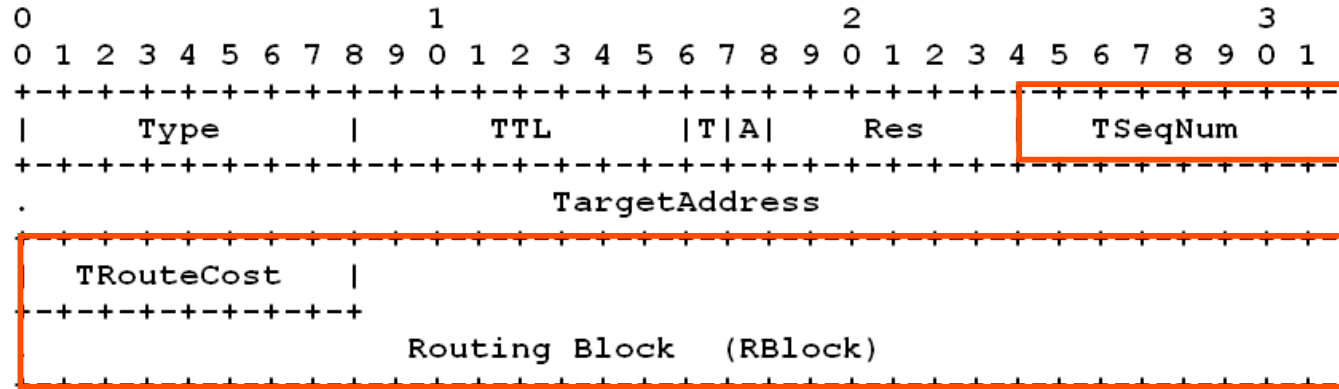


## DYMO:

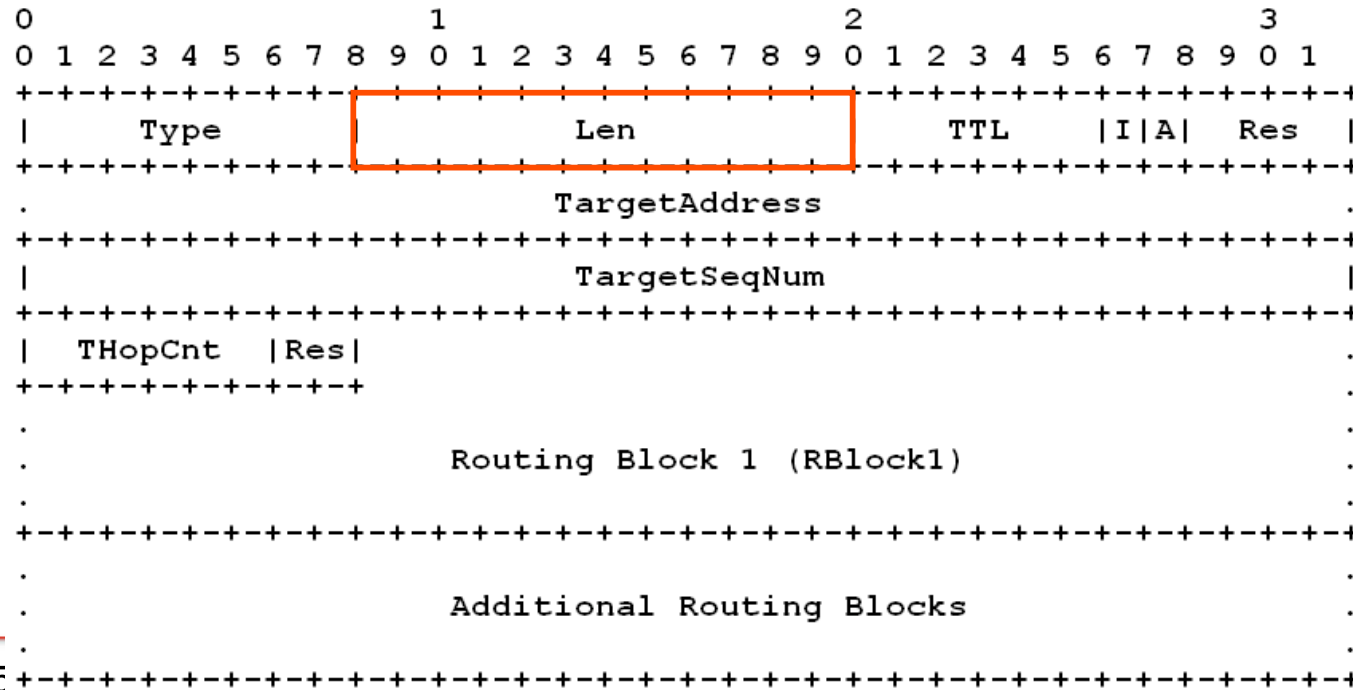


# Routing Element (RE)

DYMO-low:

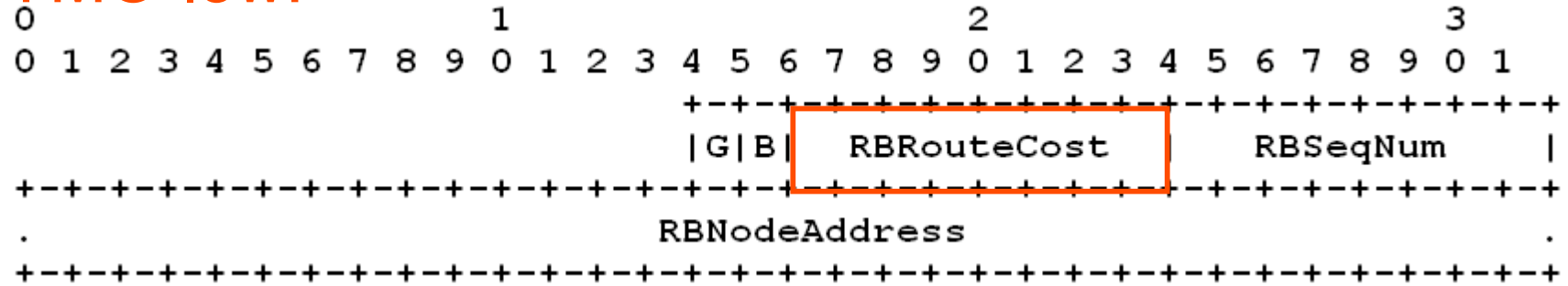


DYMO:

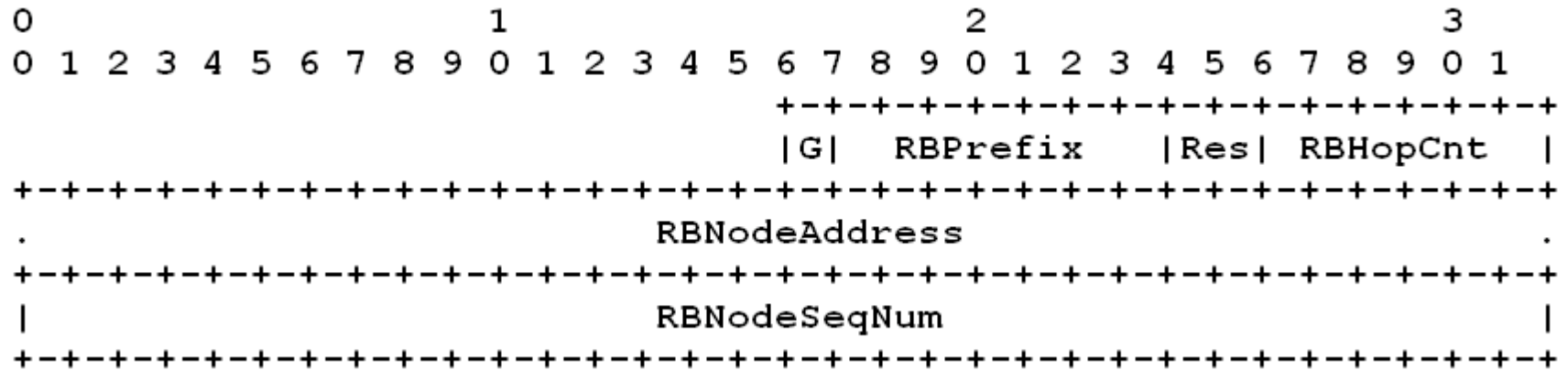


# Routing Block (RBlock)

DYMO-low:



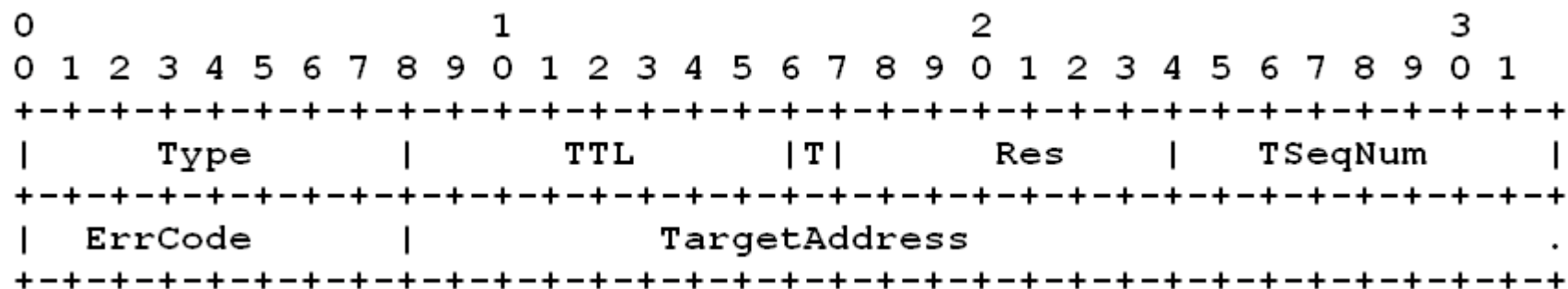
DYMO:



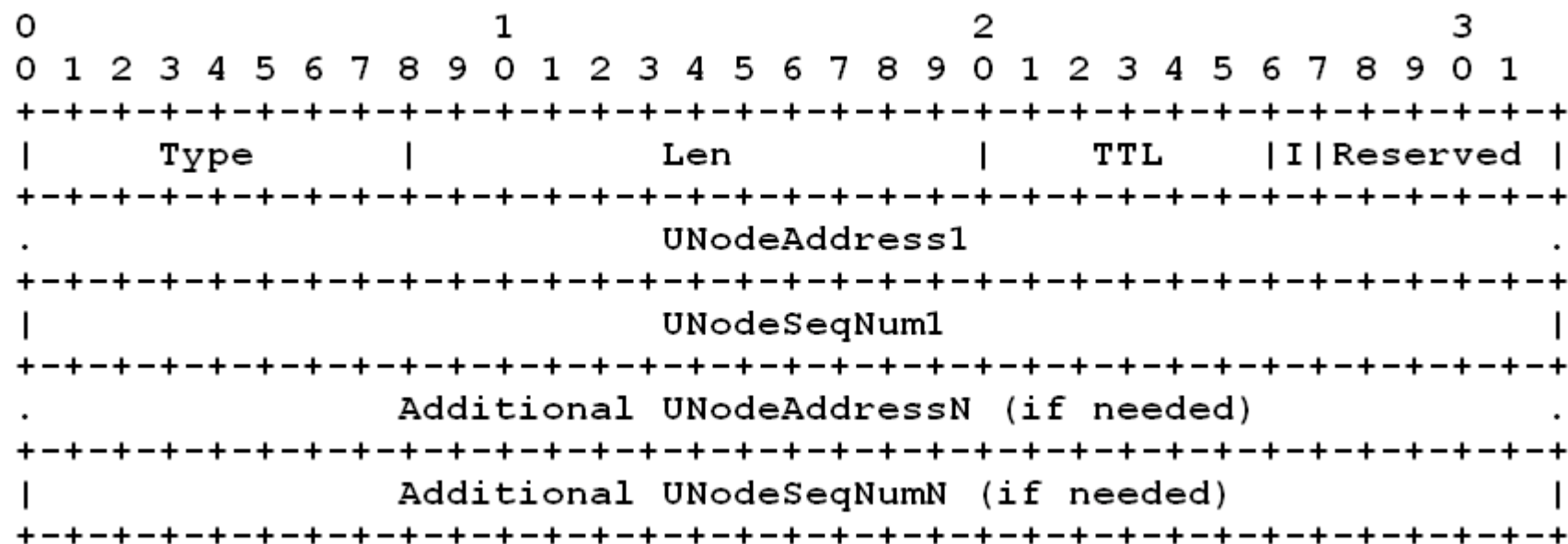


# Route Error (RERR)

DYMO-low:



DYMO:



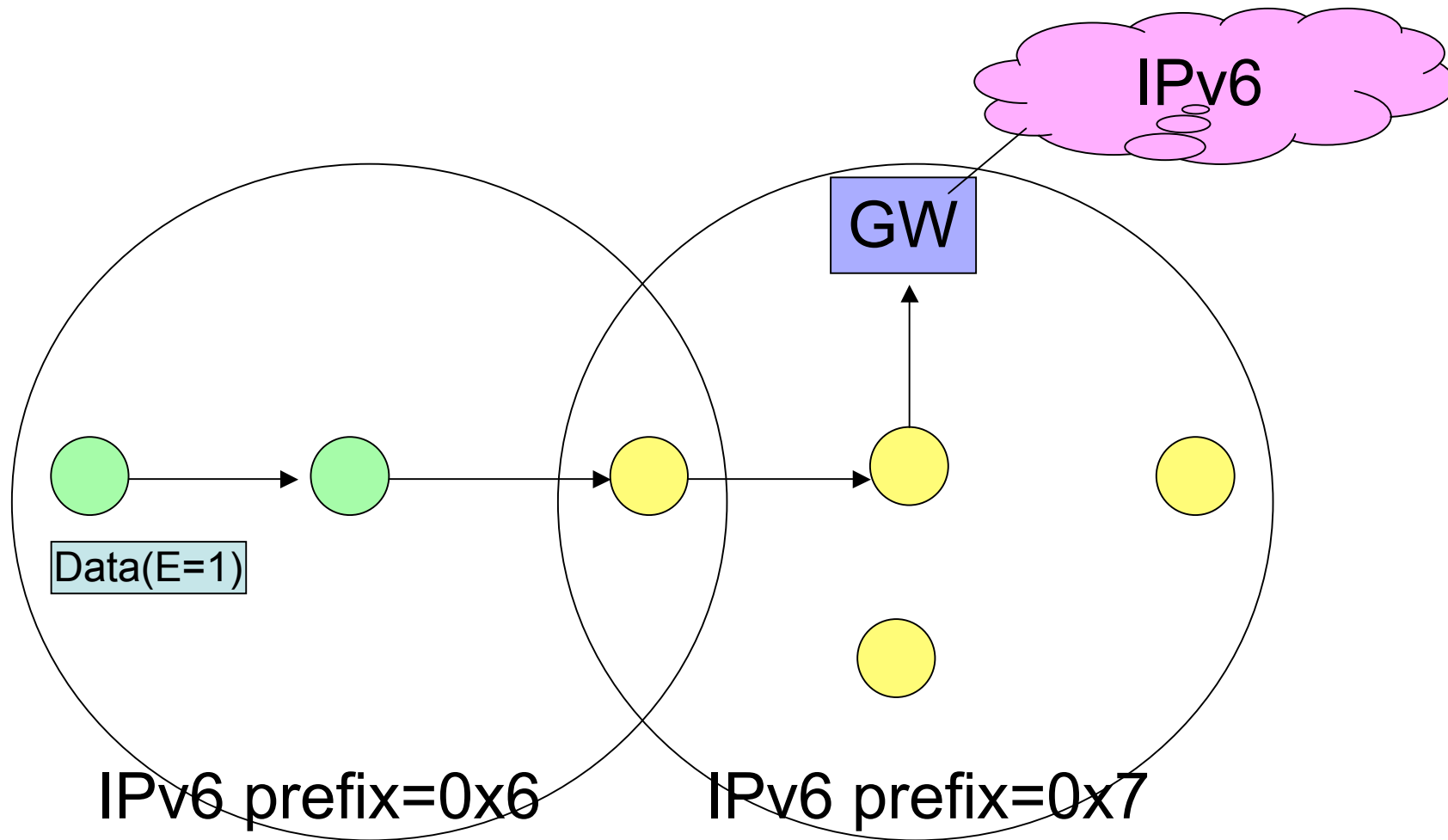
# Comparison of Routing Protocols for 6lowpan

	LOAD	DYMO-low	AODV	TinyAODV	ZigBee	AODVjr
RERR Message	Use	Use	Use	Use	Use	No Use
Sequence number	No Use	Use	Use	Use	No Use	No Use
Precursor lists	No Use	No Use	Use	No Use	No Use	No Use
Gratuitous RREP	No Use	No Use	Use	No Use	No Use	No Use
Hop count	Opt	Opt	Use	Use	No Use	No Use
Hello messages	No Use	No Use	Use	No Use	No Use	No Use
Local repair	No Use	No Use	Use	No Use	Use	No Use
Energy Usage	Low	Low	High	Low	Low	Low
Memory Usage	Low	Low	High	Low	Low	Low
Link-layer feedback	Use	Use	Opt	No	Opt	No
Mobility	Mobile/Static	Mobile/Static	Mobile	Mobile	Mobile/Static	Mobile
Control Packet Aggregation	No Use	Use	No Use	No Use	No Use	No Use

# Interoperability with Internet

- How can we route traffic to the external IPv6 network?
  - Allow **different IPv6 Prefixes** on WPANs?
    - If 6lowpan allows inter-PAN routing, this isn't enough for identifying outbound traffic to external IPv6 network
  - Use of **default GW**?
    - Add 1 bit flag(E) in the Adaptation layer format for identifying outbound traffic to external IPv6 networks → FFDs forward those packets(E=1) to the default GW.
    - GW MAY advertise itself periodically

# Handling outbound traffic to external IPv6 networks



# Open Issues

- Considering the route cost
  - Leave the route cost to be the implementation issues?
    - Parameters: Hop counts, LQI, remaining energy of nodes, etc.
- Use of the 16bit address/EUI-64 address
- Routing scalability
  - Limit the size of the 6lowpan?
- Interoperability with Internet – Default Router

6LoWPAN WG, IETF64, Vancouver

# 6LoWPAN Evaluation Results

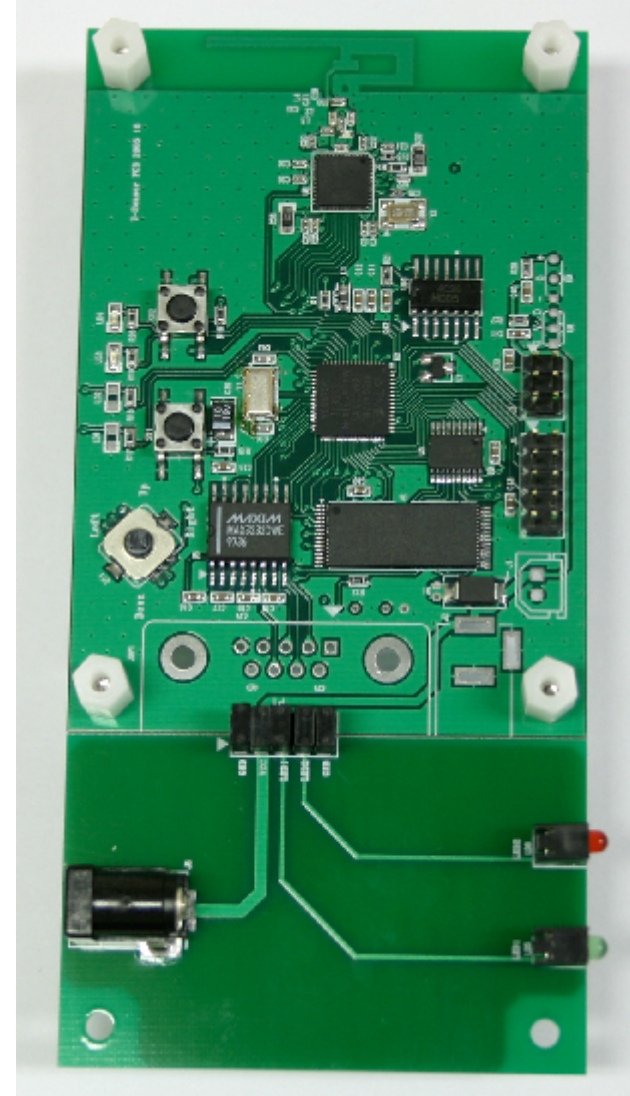
Ki-Hyung Kim (Ajou University) and  
S. Daniel Park (SAMSUNG Electronics)

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- Realization Platform
  - Implementation of 6lowpan
  - Implemented Protocol Stack
  - Preliminary Evaluation Results for Implementation
- Simulation model of 6lowpan on NS-2
  - Preliminary Simulation Results
- Hierarchical Routing Protocol (HiLow)
- Simple Service Location Protocol (SSLP)

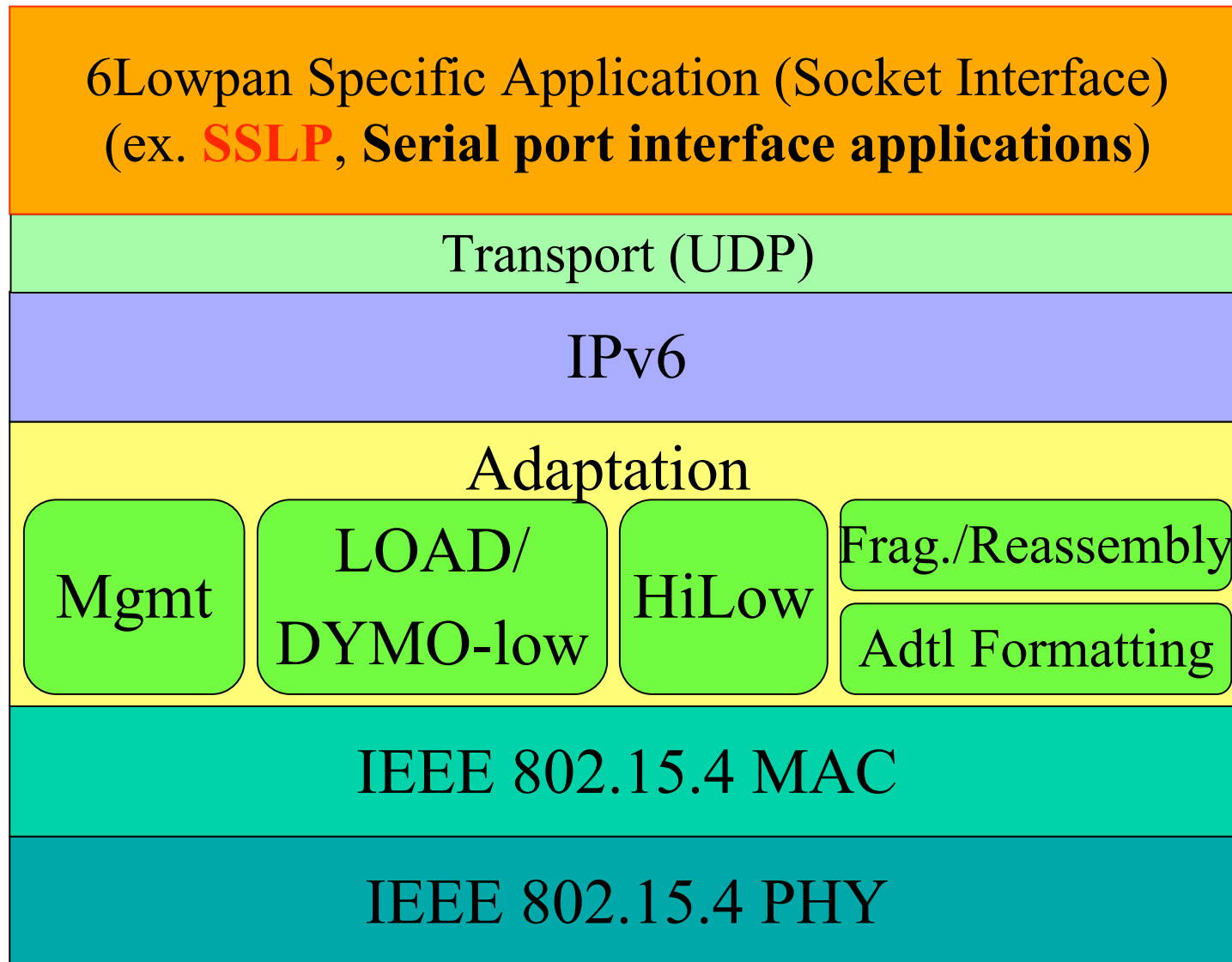
# Realization Platform

- Hardware Platform
  - Custom built prototype referenced from c2420dbk of Chipcon
    - MCU: AVR Atmega128L, MAC: Chipcon C C2420
- Implemented Protocols
  - [draft-ietf-6lowpan-format](#)
  - [draft-daniel-6lowpan-load-adhoc-routing](#)
  - [draft-daniel-6lowpan-hilow-hierarchical-routing](#)
- Currently Implementing
  - [draft-daniel-6lowpan-sslp](#)
  - [draft-montenegro-6lowpan-dymo-low-routing](#)

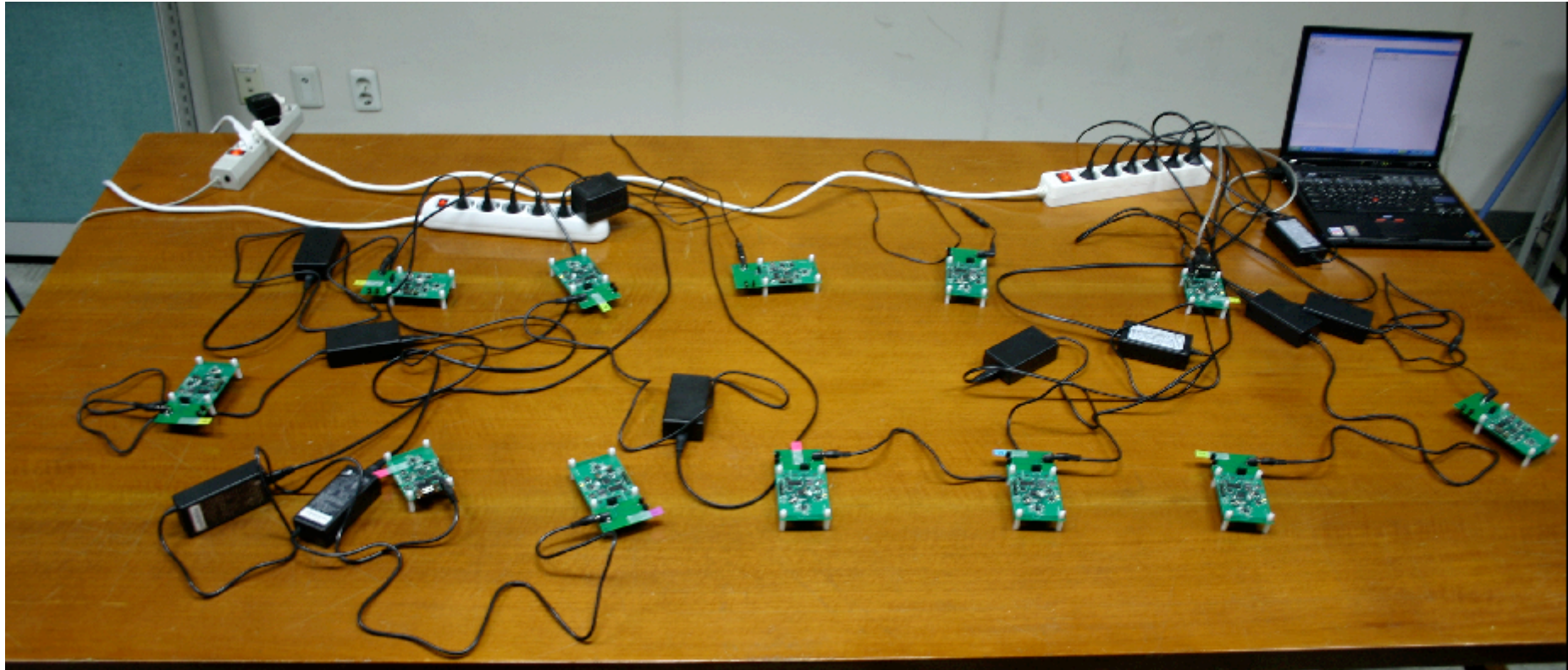




# Protocol Stack



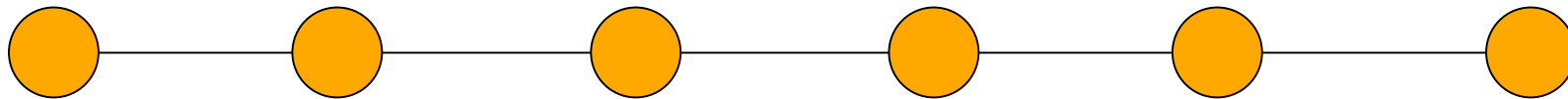
# Testbed Setup



# Topologies for Evaluation

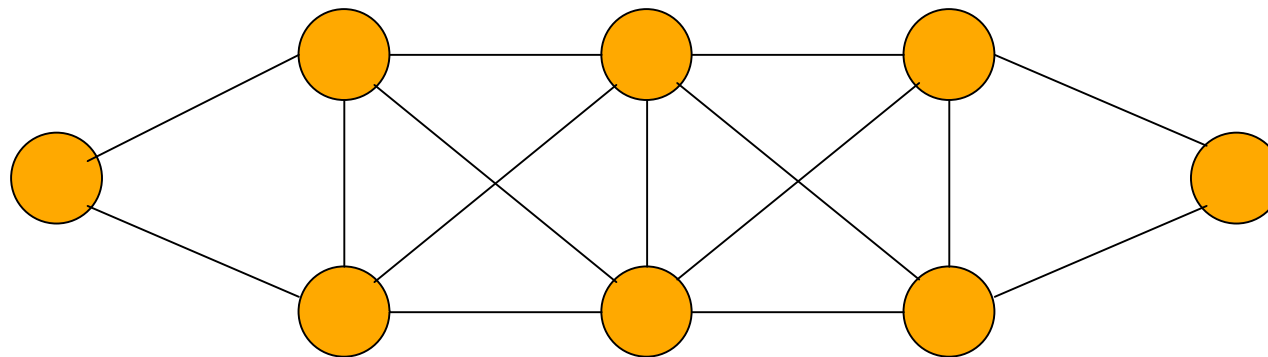
- Topology 1:

- Varying # Nodes (3, 6, 9, 12)

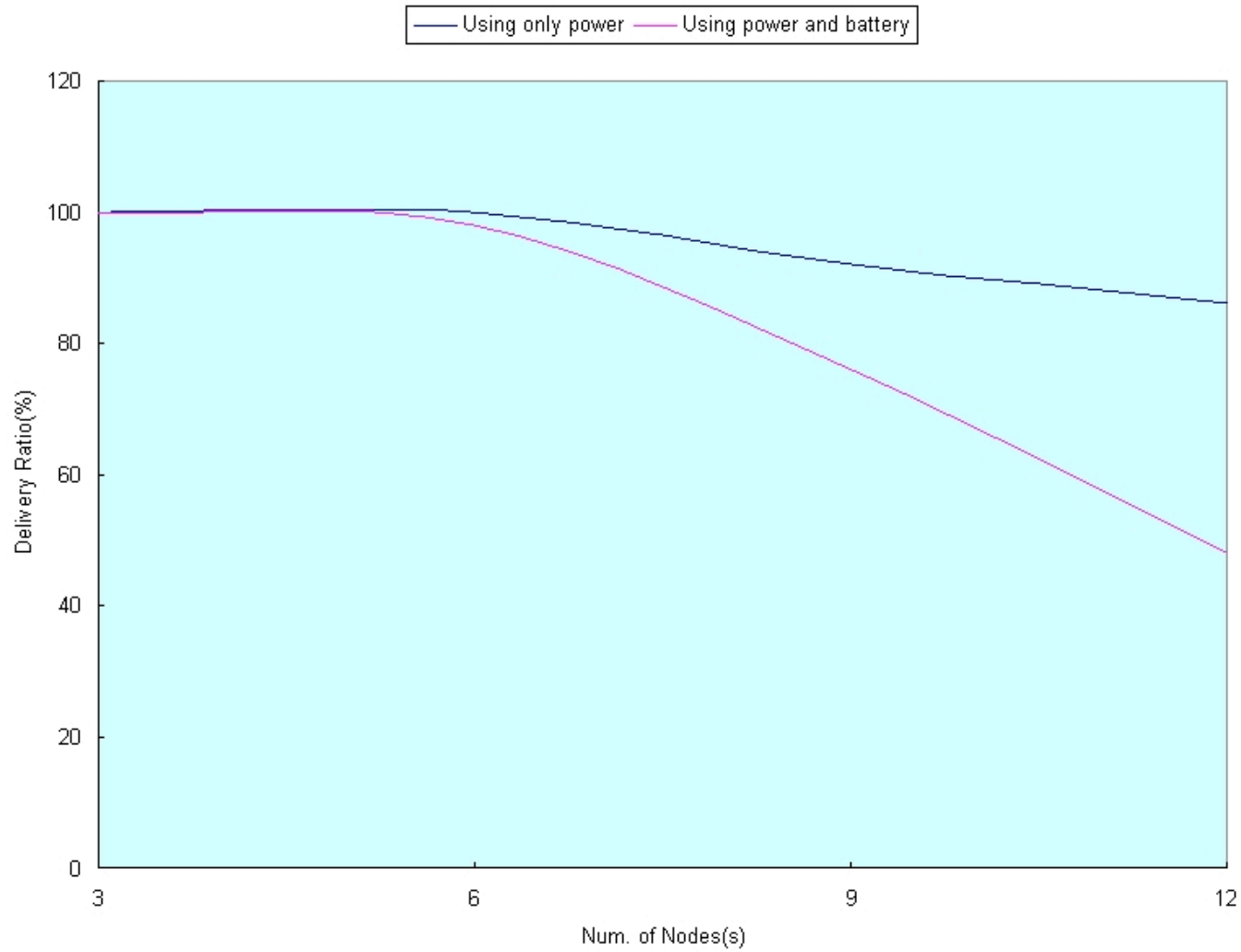


- Topology 2:

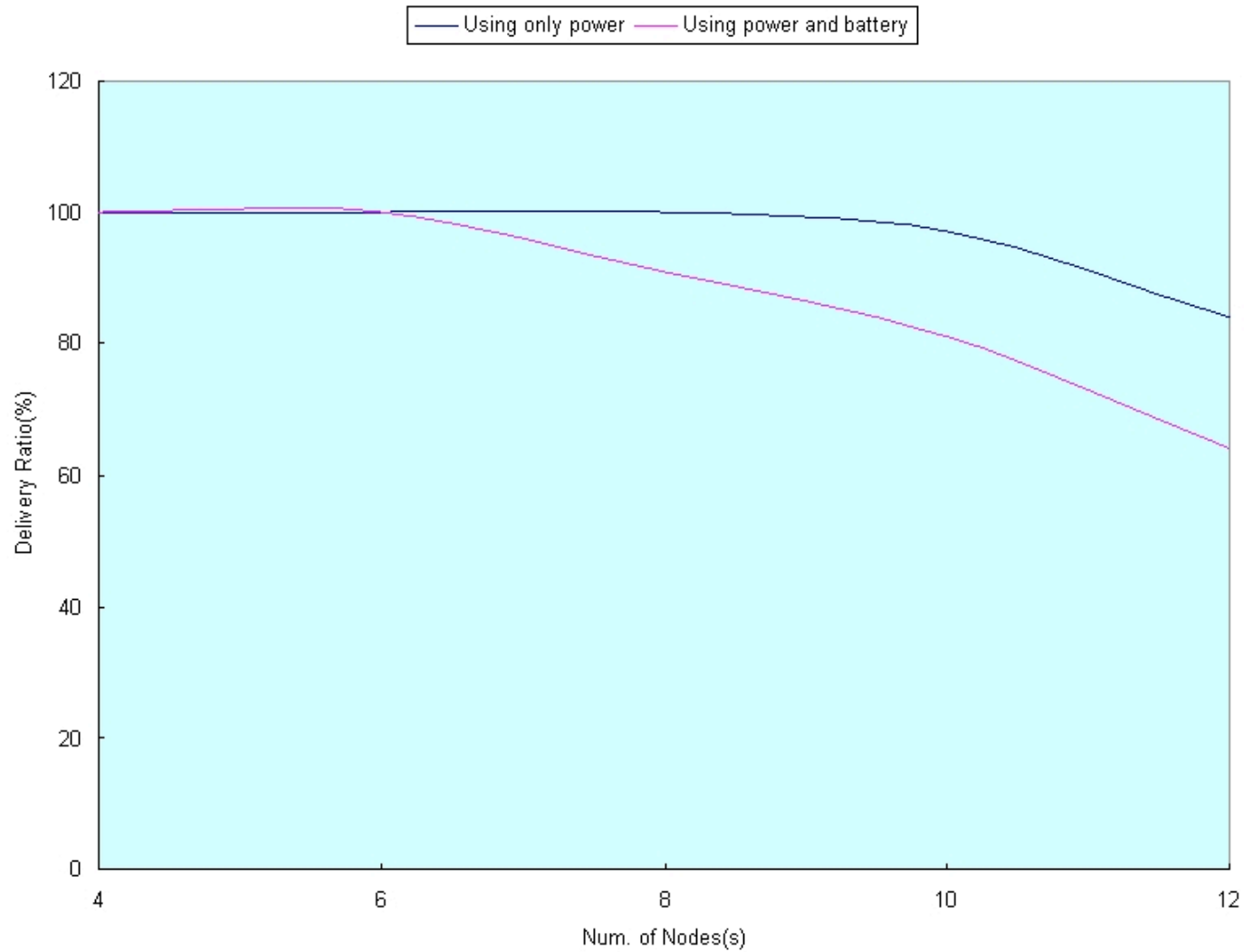
- Varying # Nodes (4,6,8,10,12)



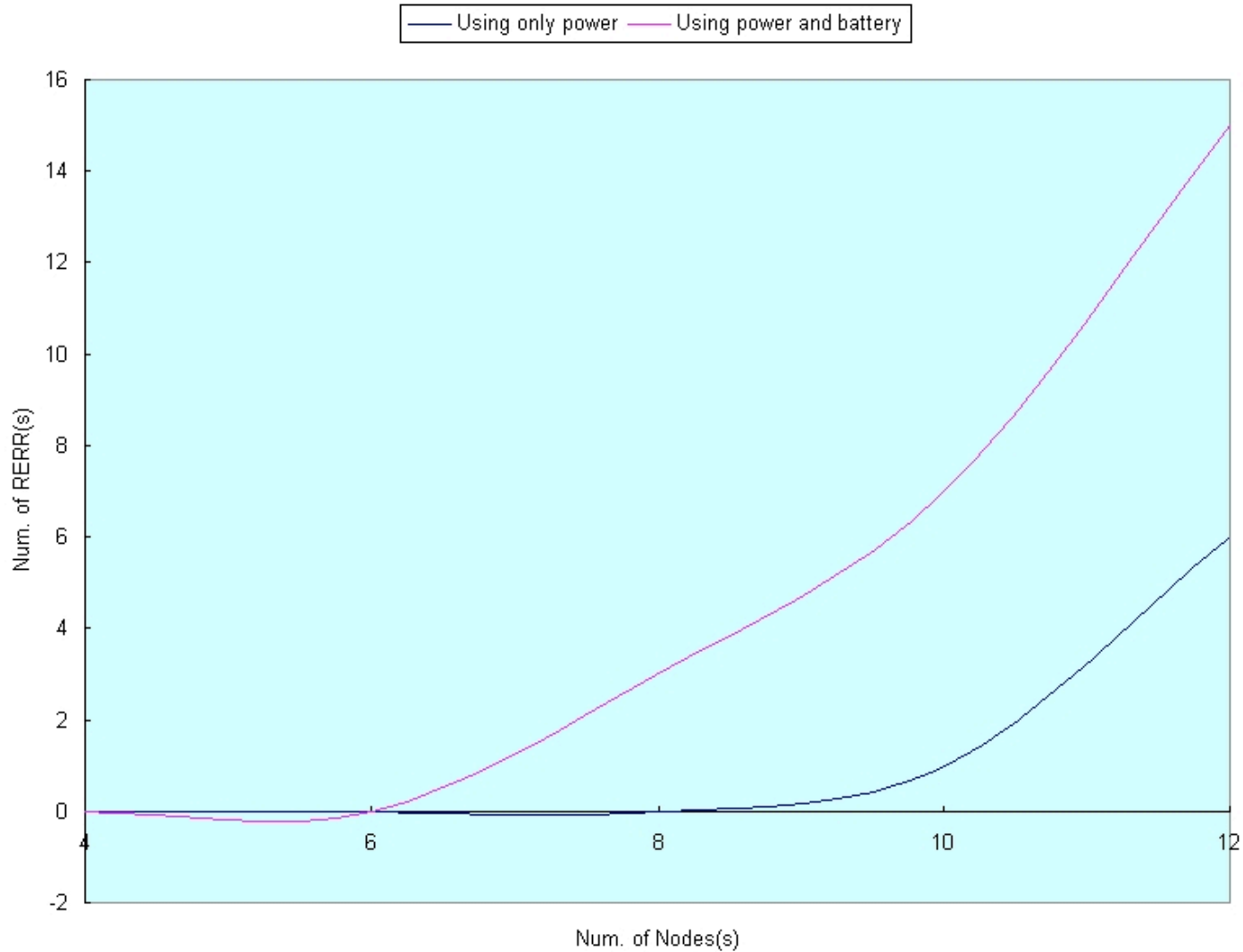
# Delivery Ratio for Topology 1



# Delivery Ratio for Topology 2

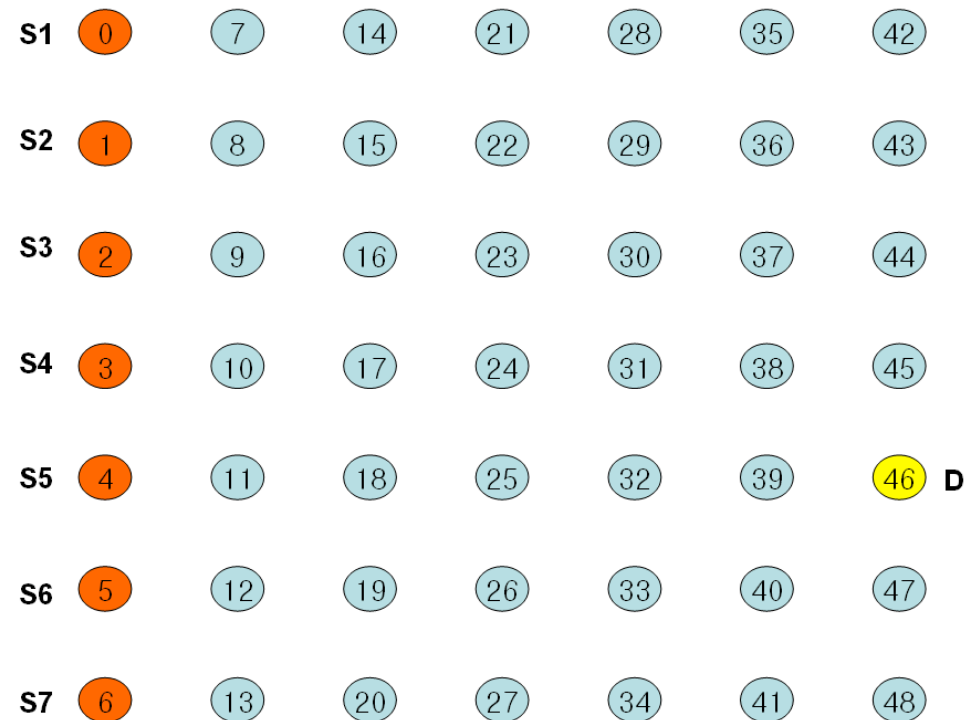


# Num. of RERRs for Topology 2

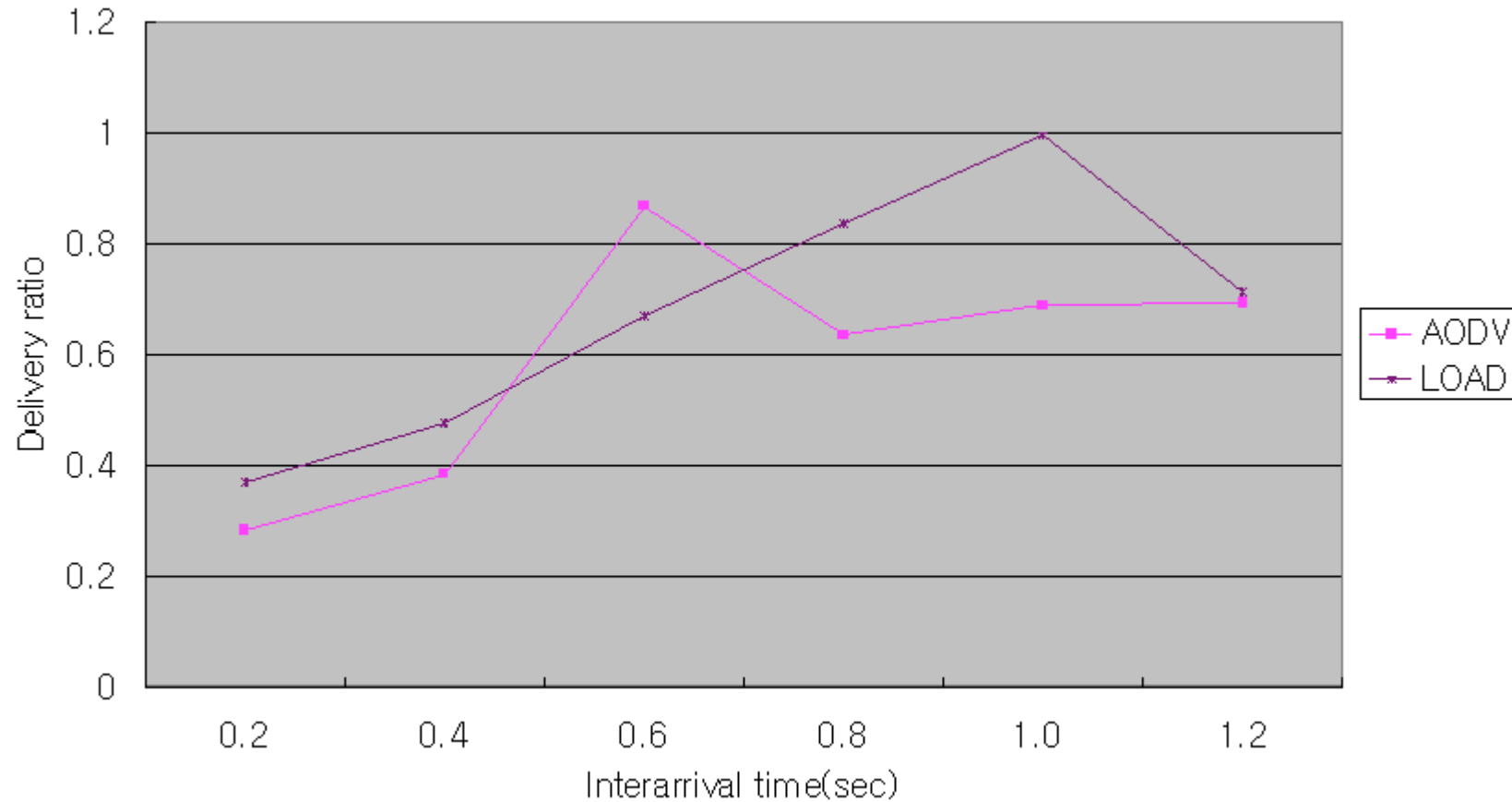


# Simulation Framework

- Implements LOAD by NS-2
- Uses IEEE 802.15.4 MAC by CUNY
- Topology
  - 7x7 Grid
  - 7 Sources
  - 1 Destination

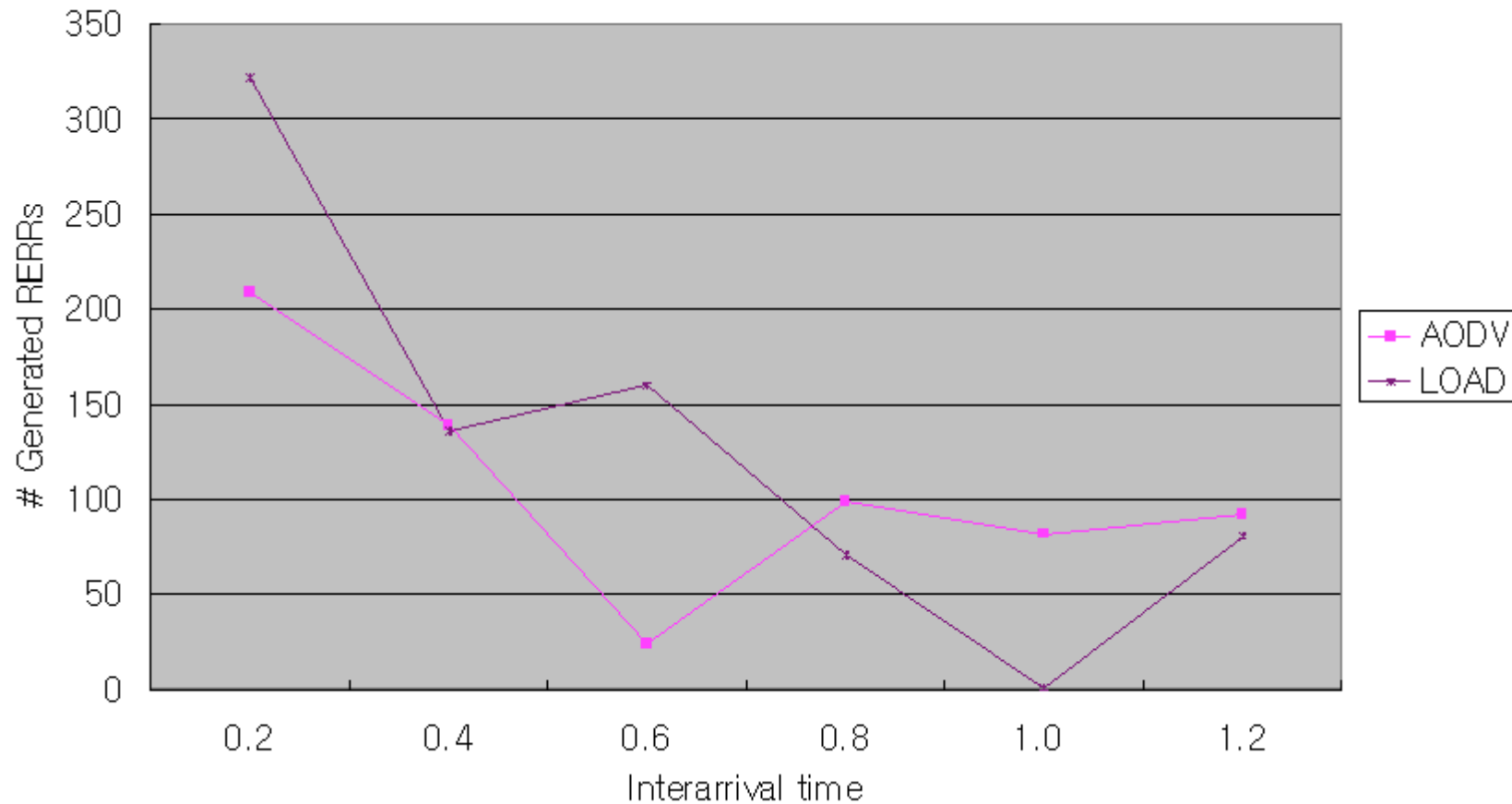


# Delivery Ratio



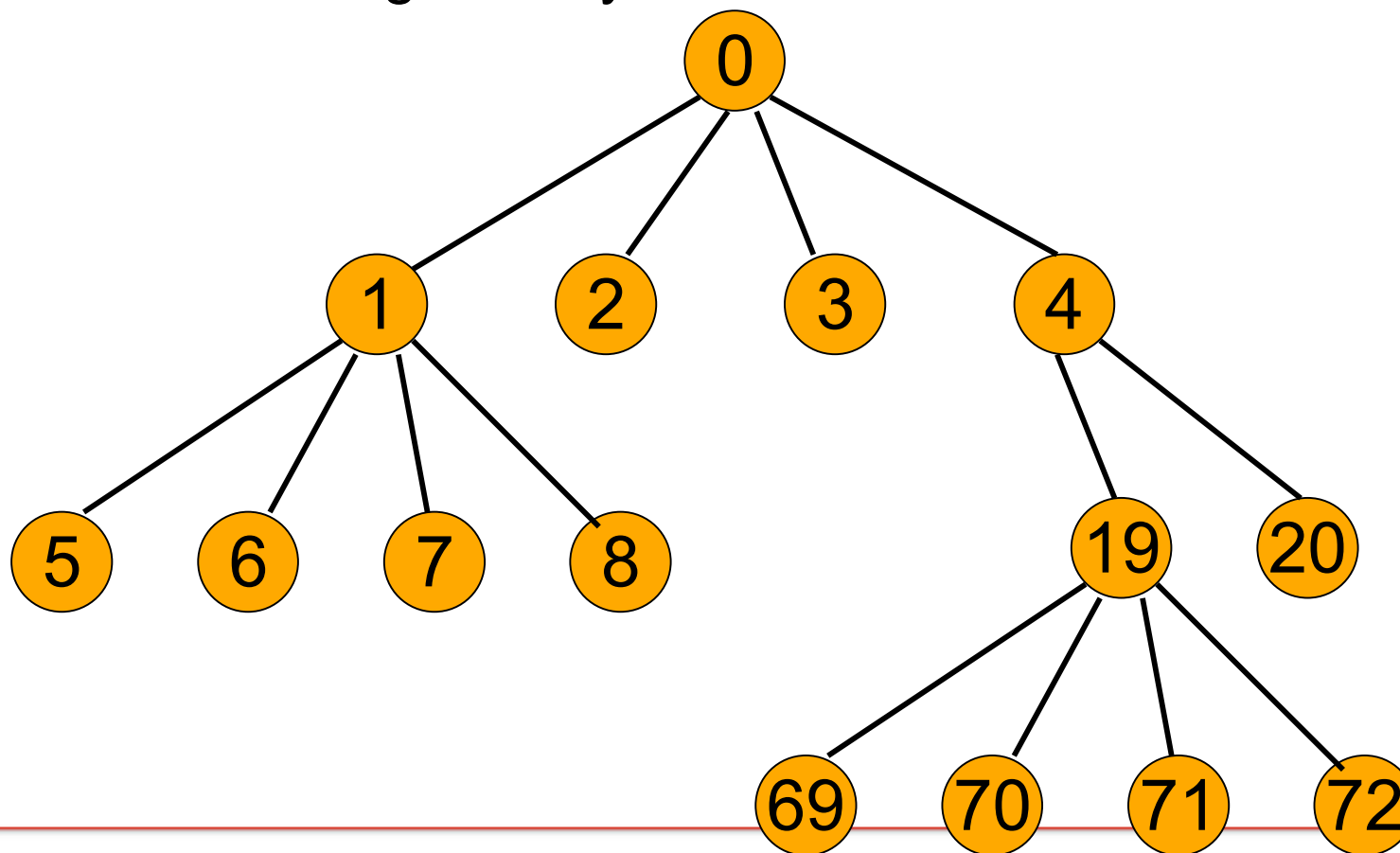


# Generated RERRs



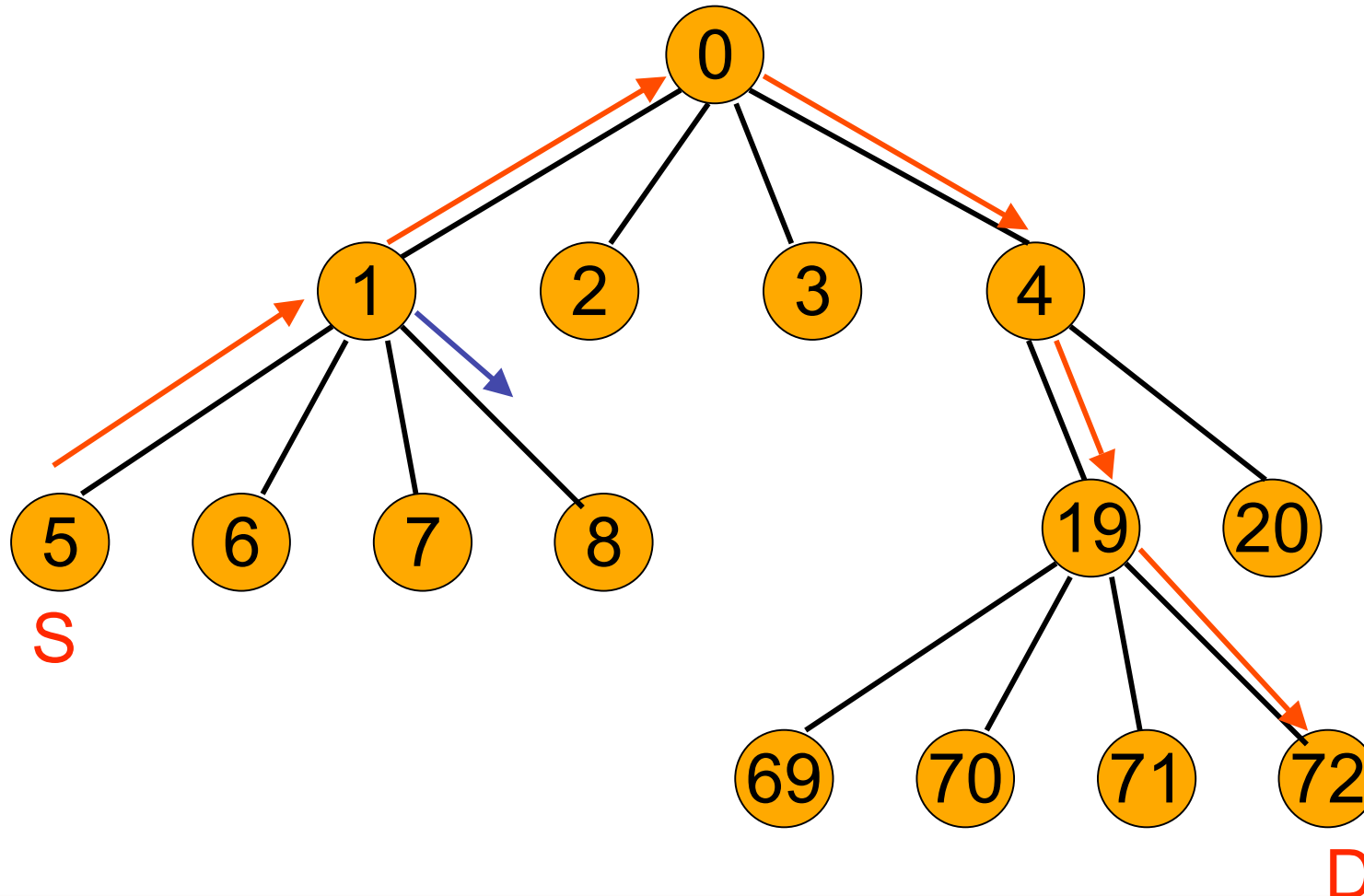
## Dynamic Assignment of Short Address (HiLow)

- No Depth Limitation of trees
  - The only parameter is MC: Maximum number of Children
  - Efficient for gradually incremental networks



# Hierarchical Routing (HiLow)

- No need of routing tables



## Routing Algorithm for HiLow

- If C is the member of SA:
  - The next hop node is  $AA(DC+1, D)$ .
- If C is the member of SD:
  - The next hop node is  $AA(DC-1, C)$ .
- Otherwise:
  - The next hop node is  $AA(DC-1, C)$ .

, Where  $AA(D, k)$  : the address of the ascendant node of depth D of the node k

SA, SD: Sets of ascendant nodes and descendant nodes

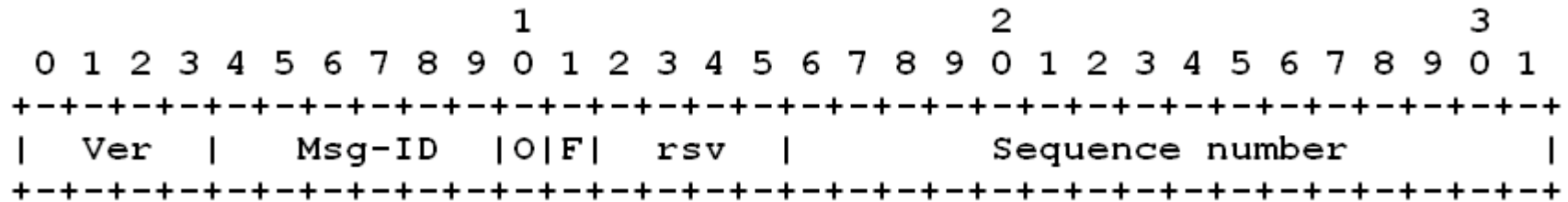
C: Current node

# Simple Service Location Protocol(SSLP)

- When 6lowpan nodes come in close proximity, they need to locate one another and services in proximity
- Related Works
  - SLPv2 in Internet
  - SSDP(Simple Service Discovery Protocol) of UPnP
  - Jini
- These are not suitable for 6lowpan
  - Limited packet size
  - Limited processing power
  - Dynamic nature of network topology
- SSLP
  - Provides mechanisms for locating services and peer nodes in proximity
  - Interoperates with SLPv2 on Internet

# SSLP Header Format (1)

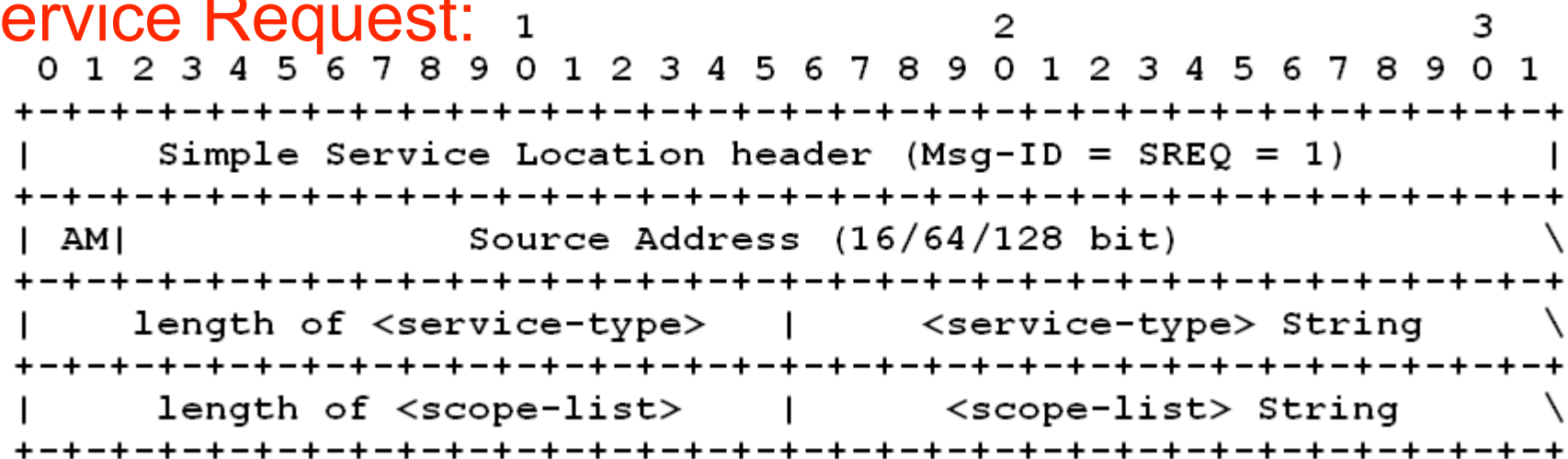
- SSLP General Header



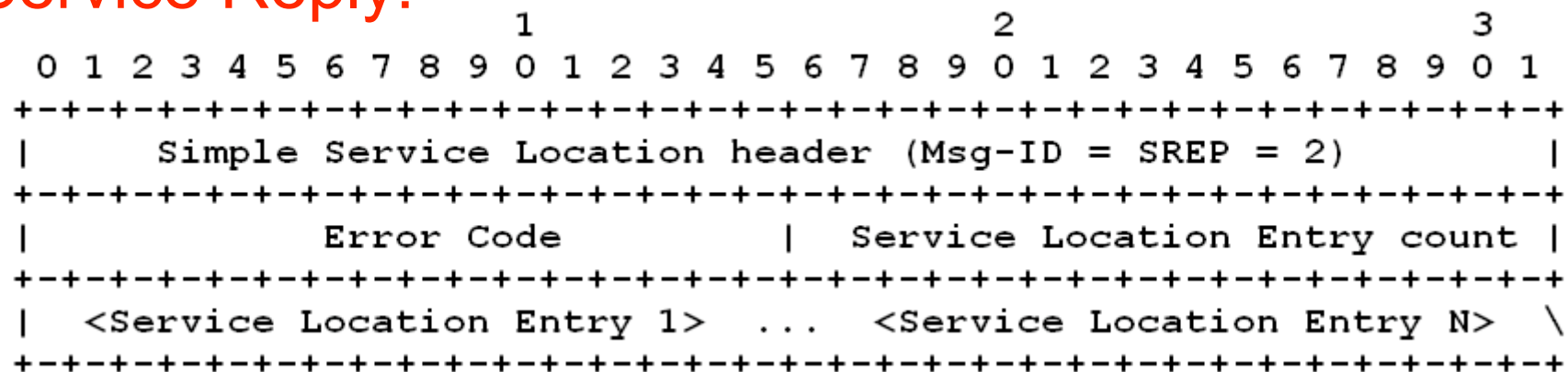
- Message Type    Abbreviation    Msg-ID
- Service Request            SREQ            1
- Service Reply              SREP            2
- Service Registration      SREG            3
- Service Deregistration    SDER            4
- Service Acknowledge       SACK            5
- DA Advertisement          DADV            6
- SA Advertisement          SADV            7

# SSLP Header Format(2)

## Service Request:



## Service Reply:



## Next steps

- Feedback is welcome
- Any comments/suggestions?