Survivability and Scalability of Space Networks

Mohammed Atiquzzaman
School of Computer Science
University of Oklahoma.

Md. Shohrab Hossain
William Ivancic

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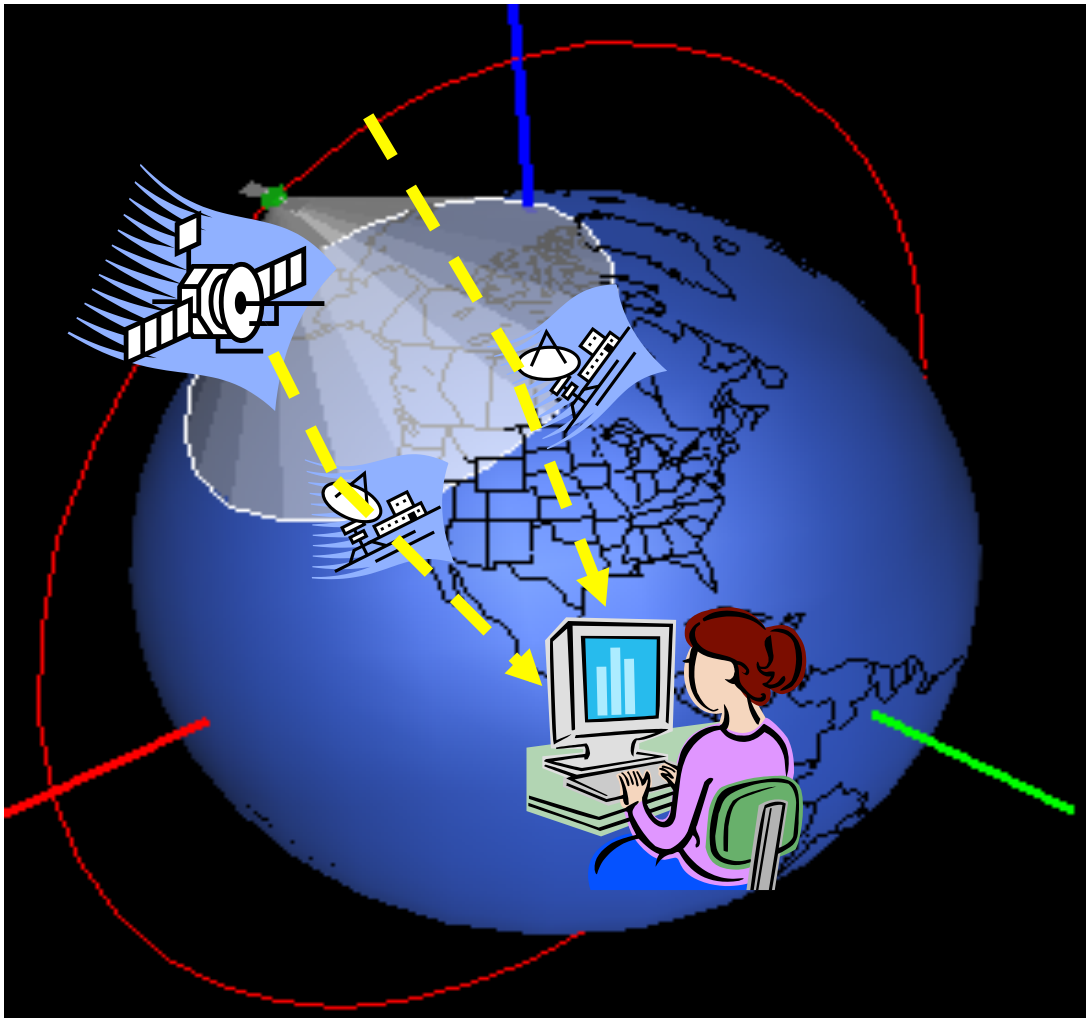
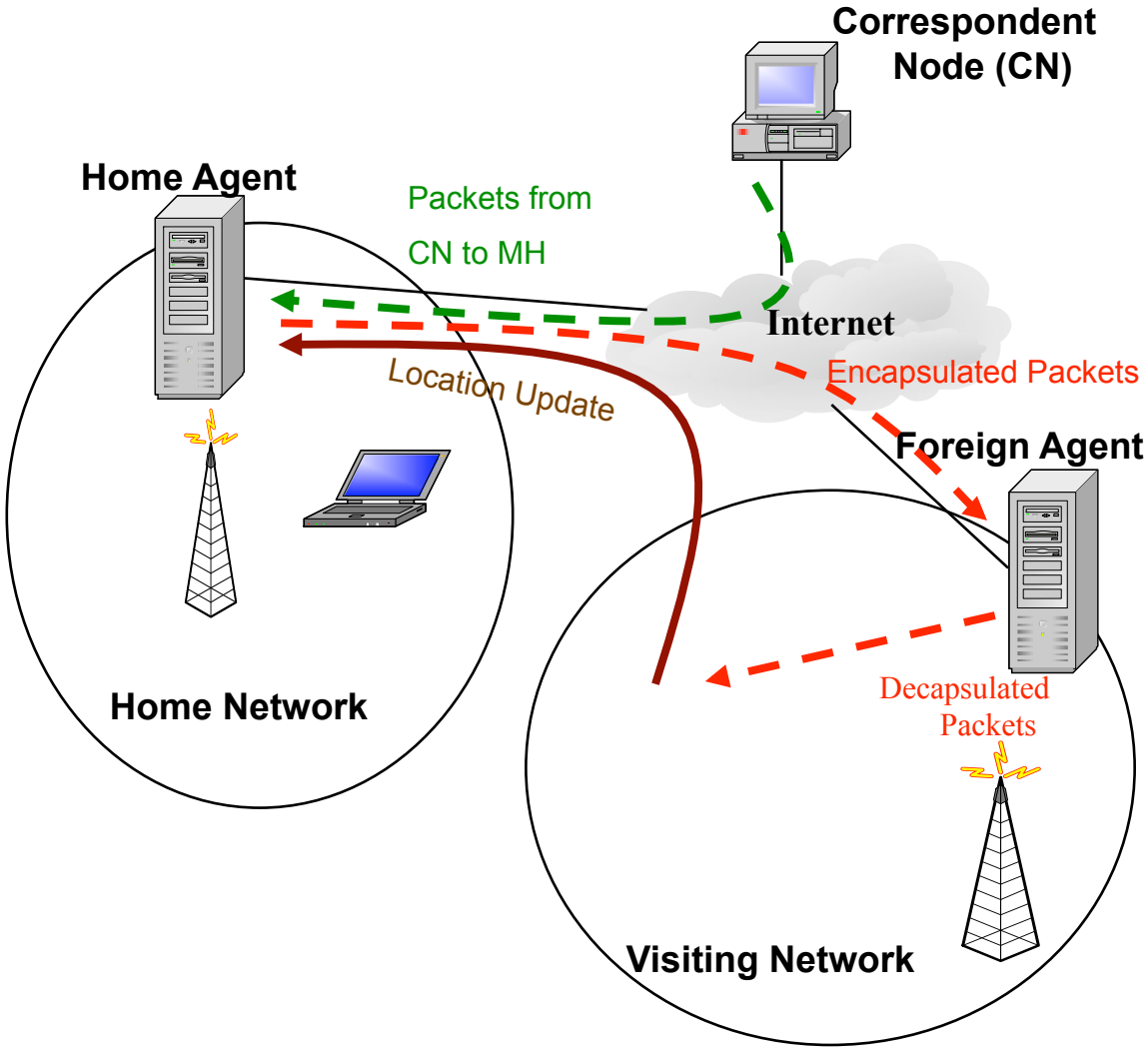
Motivation for mobility protocols

- Onboard Satellite equipments need to communicate with control centers
- Ground stations provide different IP prefix to Satellite
- Need to maintain continuous connection with remote computer

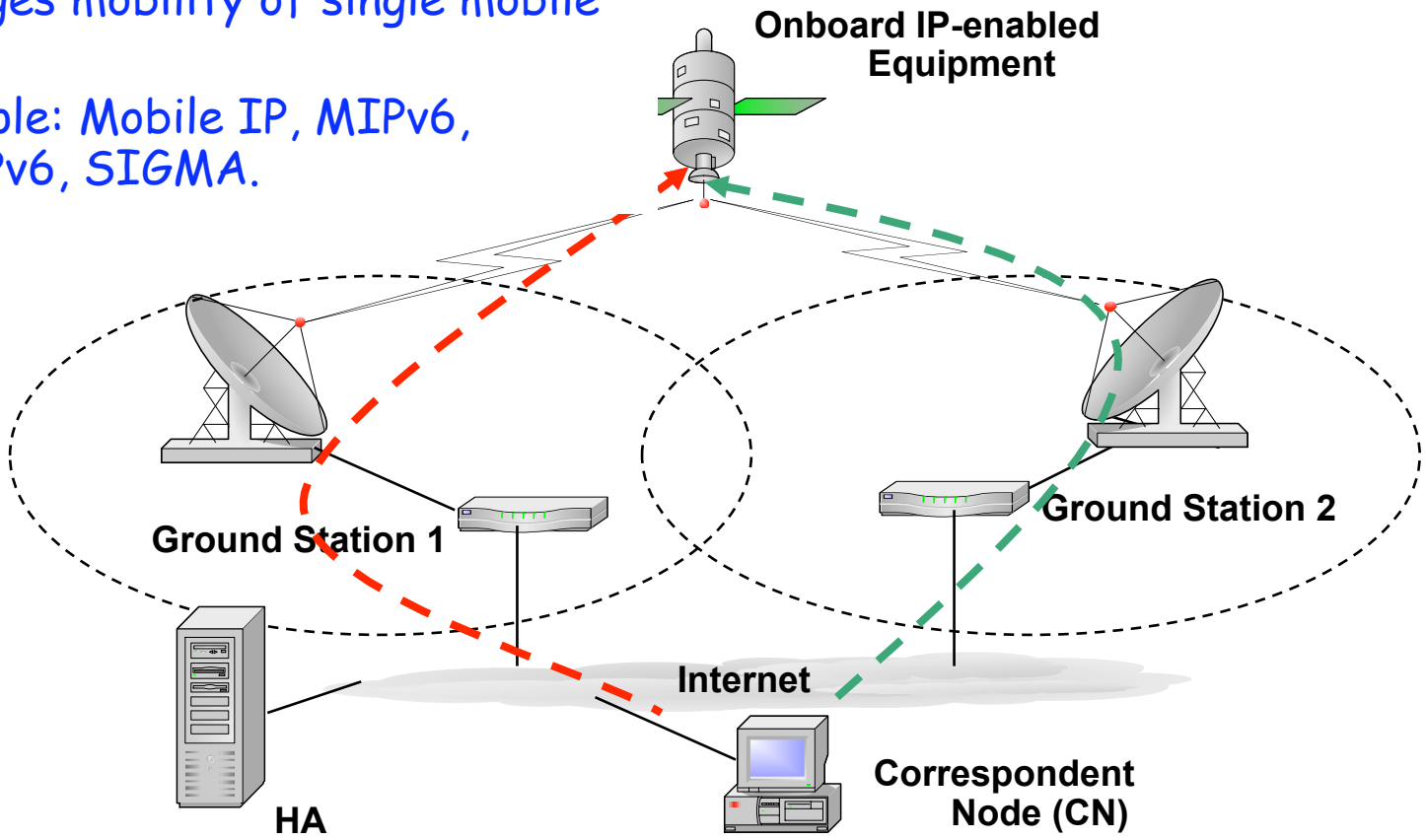


- Employs mechanism similar to postal service mail forwarding



Satellite as Mobile Host / Network

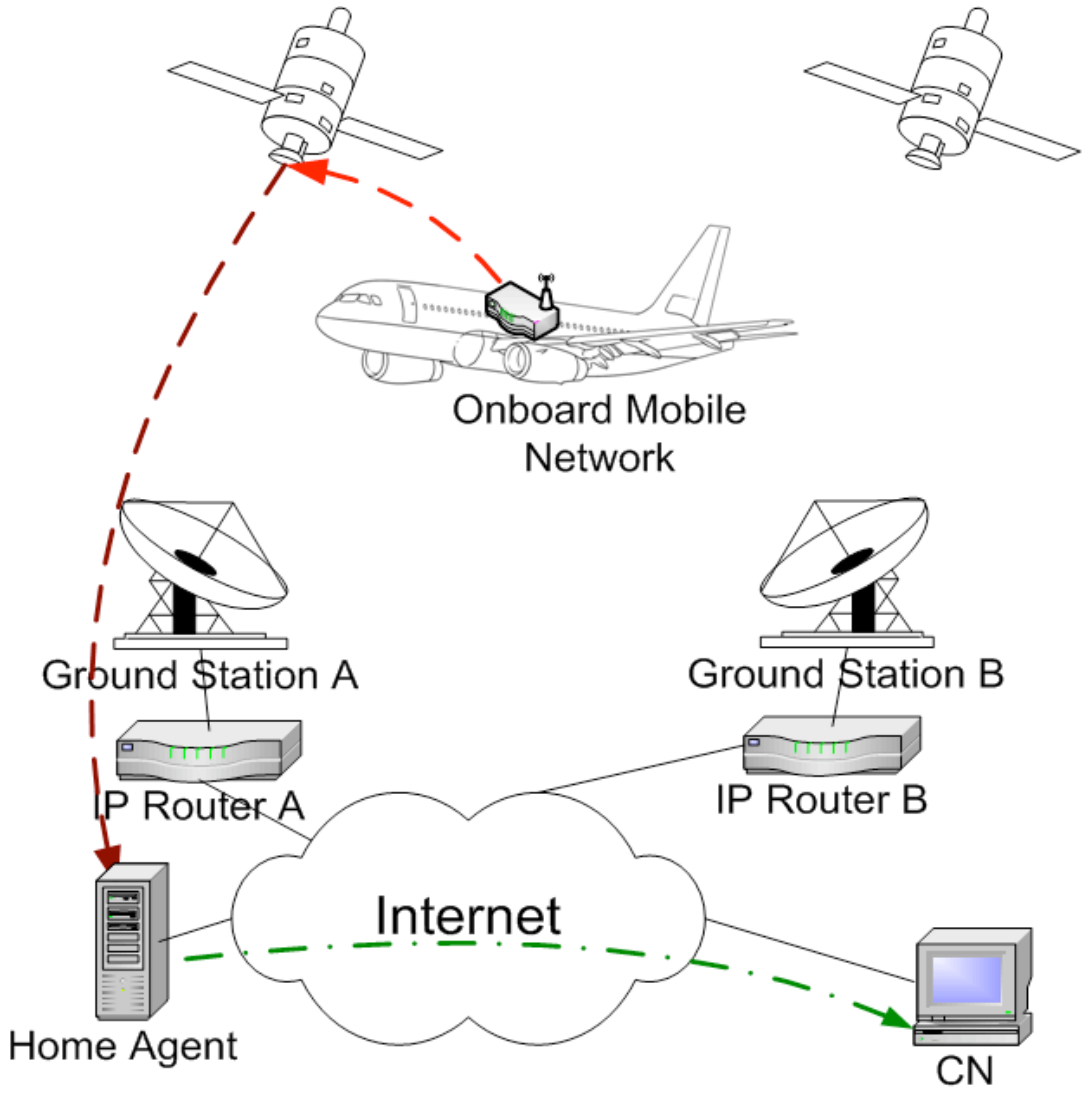
- Manages mobility of single mobile host.
- Example: Mobile IP, MIPv6, HMIPv6, SIGMA.



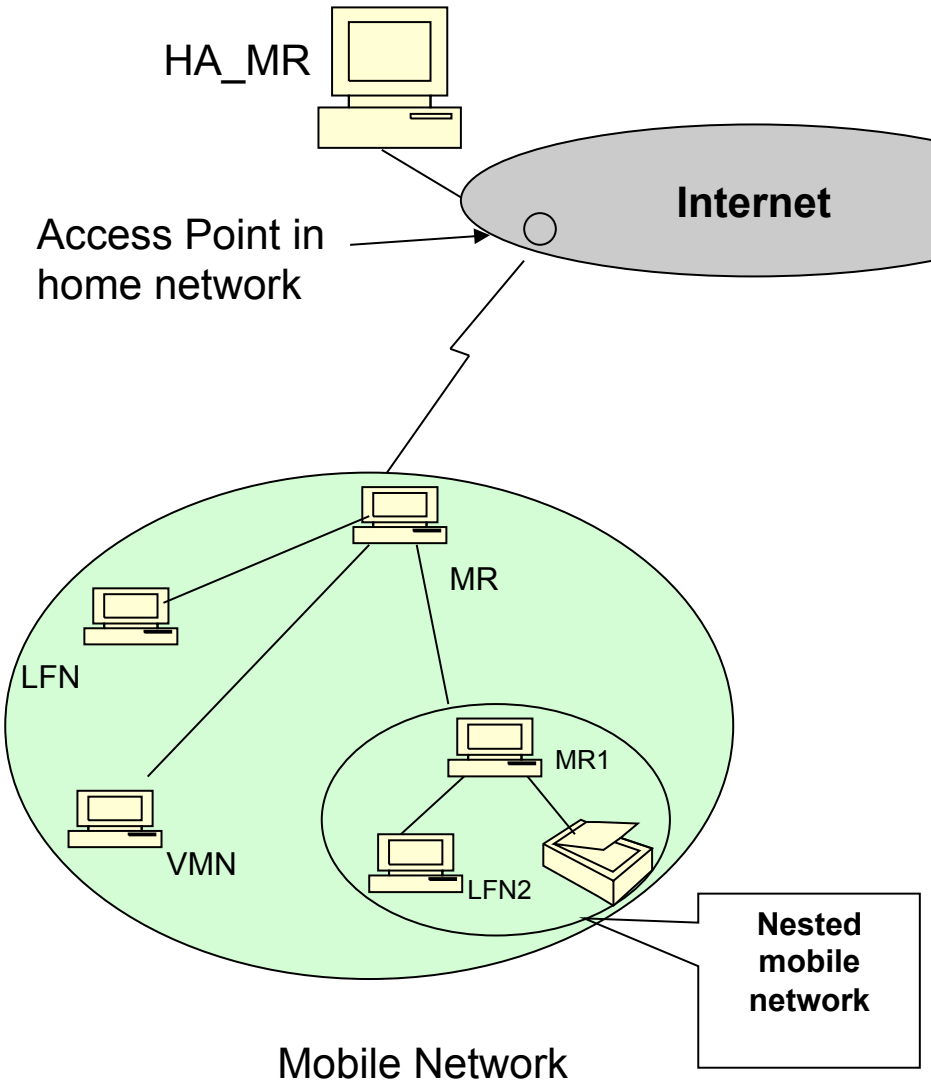
- Satellite with IP-enabled equipment acts as mobile host / network.
- Ground stations works as Access Points.

Satellite as a router

- Satellites can act as routers in the Internet.
- Can provide IP-connectivity to Mobile hosts / network in other spacecrafts or in remote location on earth.

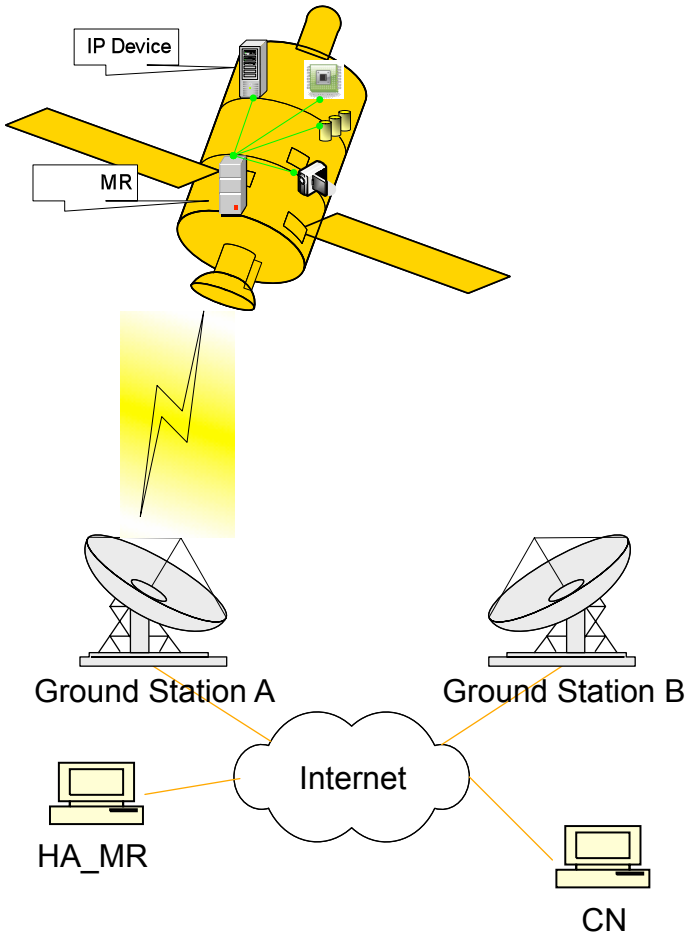


NEMO: Architecture



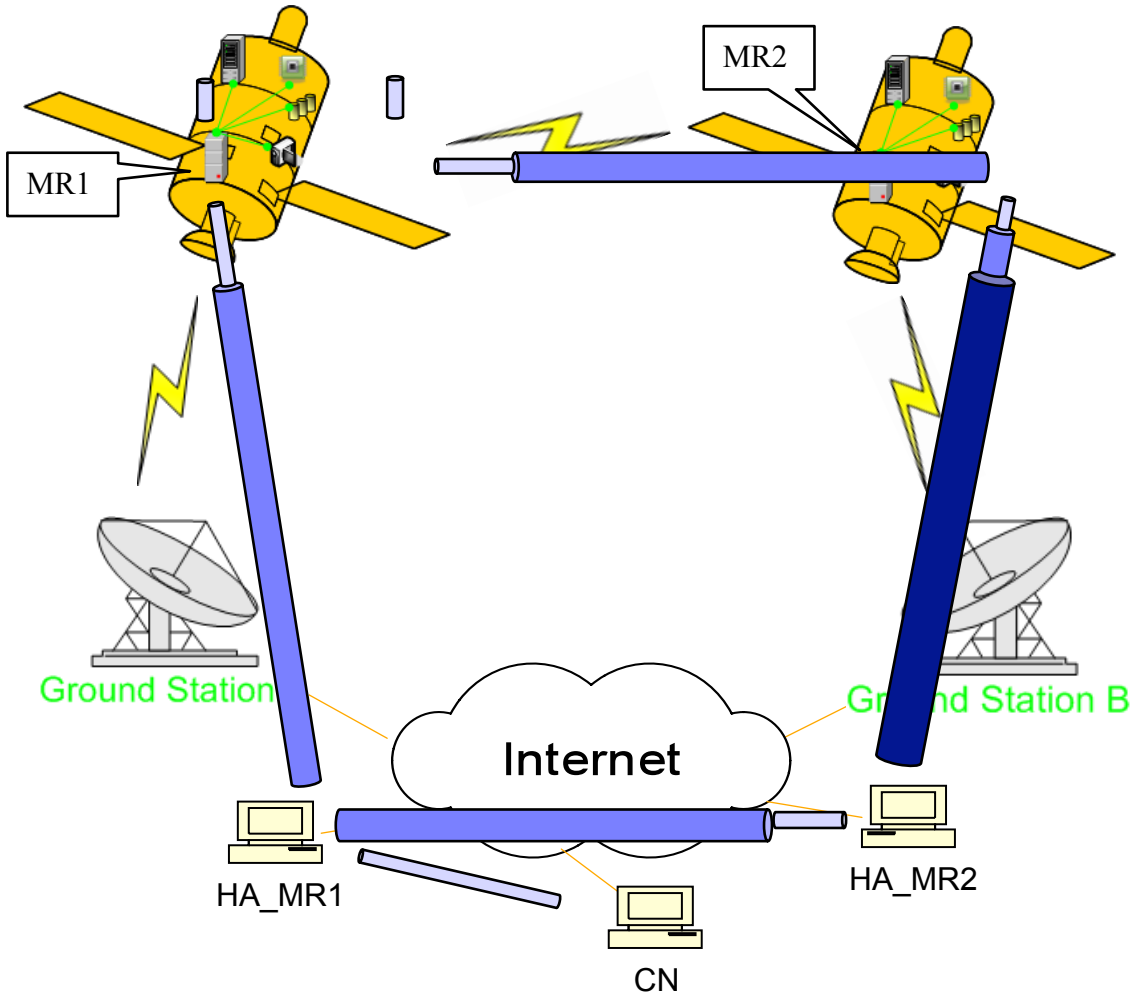
- Mobile network: Devices that move together are connected to form a network.
- Mobile Router (MR): Gateway for all devices inside the mobile network. Performs location update on behalf of all devices.
- Home network: Network to which mobile network is usually connected.
- Home Agent (HA_MR): A router in home network. Tracks the location of mobile network and re-directs packets to mobile network.
- Nested mobile network: A mobile network connected to another mobile network.

- Satellites containing many IP-enabled devices → network in motion.
- On-board network hands off between ground stations.



Nested NEMO in satellite networks

- Nested NEMO can be used to continue IP connectivity.



Saratoga: A file transfer protocol for space networks

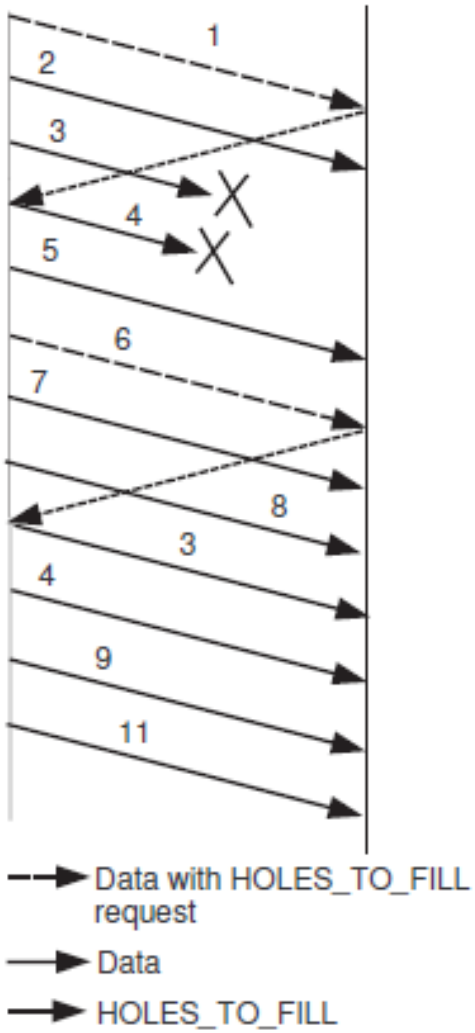
- TCP is not suitable for file download from satellites using asymmetric bandwidth links.
- Saratoga, a file transfer protocol developed by NASA, Cisco and SSTL, increases the download throughput by reducing the dependency of data transfer on acknowledgements

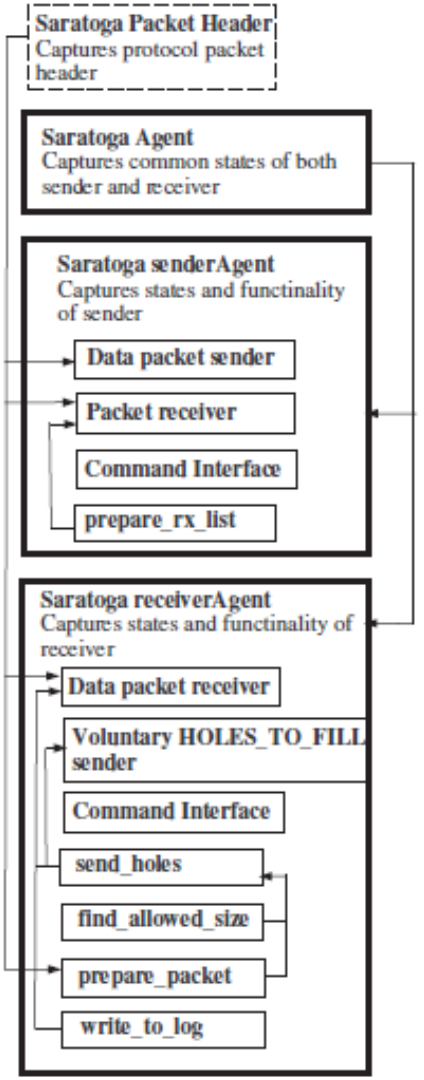
- Try to send as much data as possible based on link capacity
  - Ÿ Not effected by loss
- ACK requested by sender periodically
  - Ÿ Period determined based on reverse link capacity to avoid bottleneck
- Capable of resumption of data delivery
- Work over UDP
- Future version will have provision for congestion control

Saratoga
UDP
IP
LINK
PHY

Saratoga implementation in ns-2

- TCP is not suitable for file download from satellites using asymmetric bandwidth links.
- Saratoga, a file transfer protocol developed by Cisco and SSTL, increases the download throughput by reducing the dependency of data transfer on acknowledgements
- We have implemented a number of Saratoga features in ns-2.
- The implementation will help us study data download rates from satellites using Saratoga.
- **Cisco is partly funding development of Saratoga in ns-2 through a separate grant.**



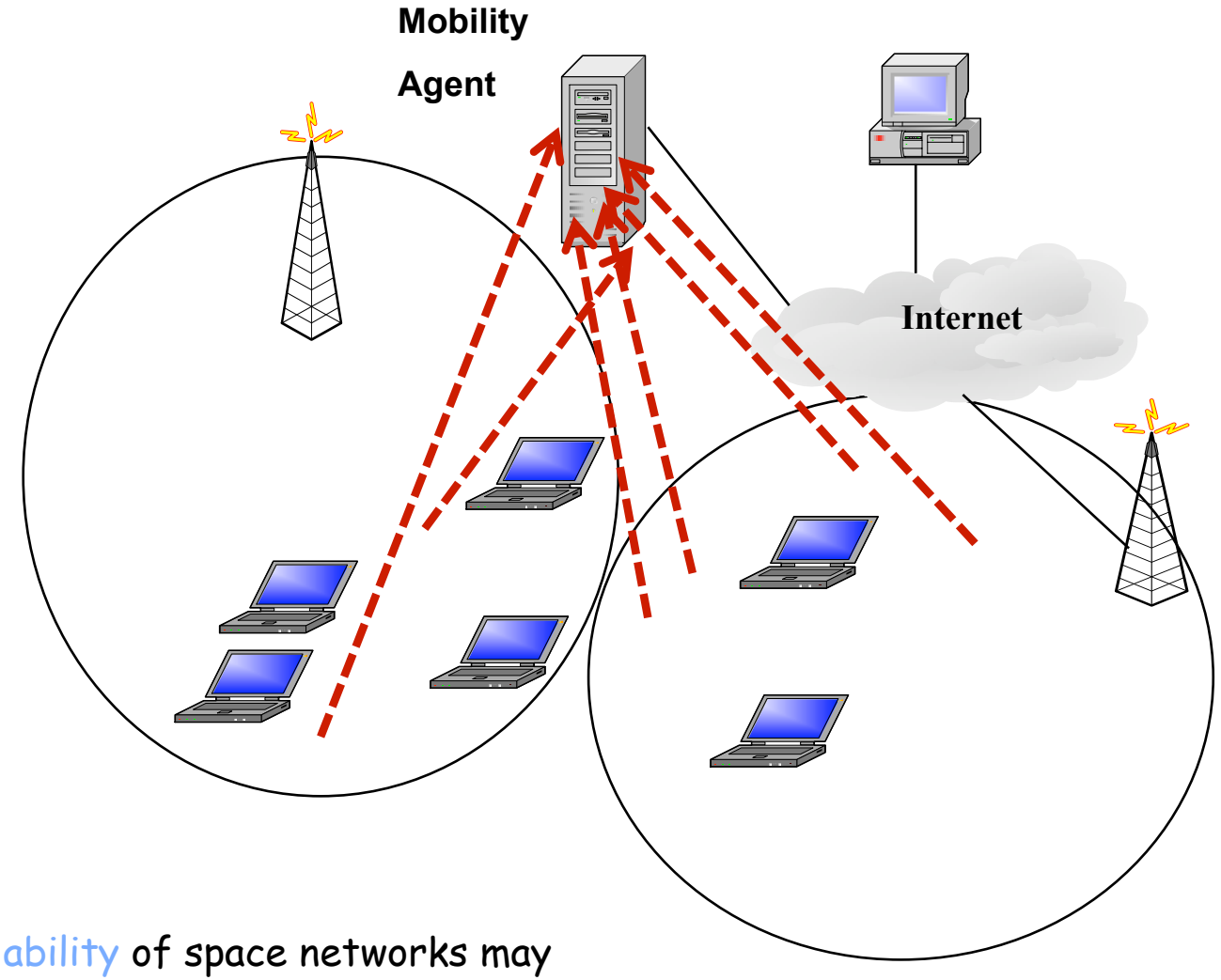


Saratoga implementation overview

Complete feature list of Saratoga			Feature type	Implementation status		
				Implemented	To be implemented	Not to be implemented
Sender side	Sending BEACON		Optional	√		
	Handshaking	Start data transfer from either sender or receiver	Required	√		
		Resumption of data transfer	Required	√		
		Delete request	Required			√
		Data transfer rejection	Required			√
	Data sending	Basic	Required	√		
		Data transfer with some error	Optional			√
		Multicasting	Optional			√
		Streaming	Optional			√
	Loss recovery by retransmission		Required	√		
	Connection termination at inactivity		Required	√		
	Congestion control		Optional		√ (TFRC or any new congestion control)	
	Dynamic ACK timing		Proposed	√ (Determine when to send request for ACK)		
Receiver side	Connection setup by handshaking		Required	√ (To start or resume data transfer)		
	Loss recovery by keeping track of lost packet and sending ACK		Required	√		

Survivability and scalability issues

- Future space networks:
  - LEO spacecrafts will contain many IP-enabled devices
  - Large number of clients accessing satellite data.



- Survivability and scalability of space networks may become a major issue.
- Increased number of nodes will overload **mobility agents** with *signaling* and *data packets*

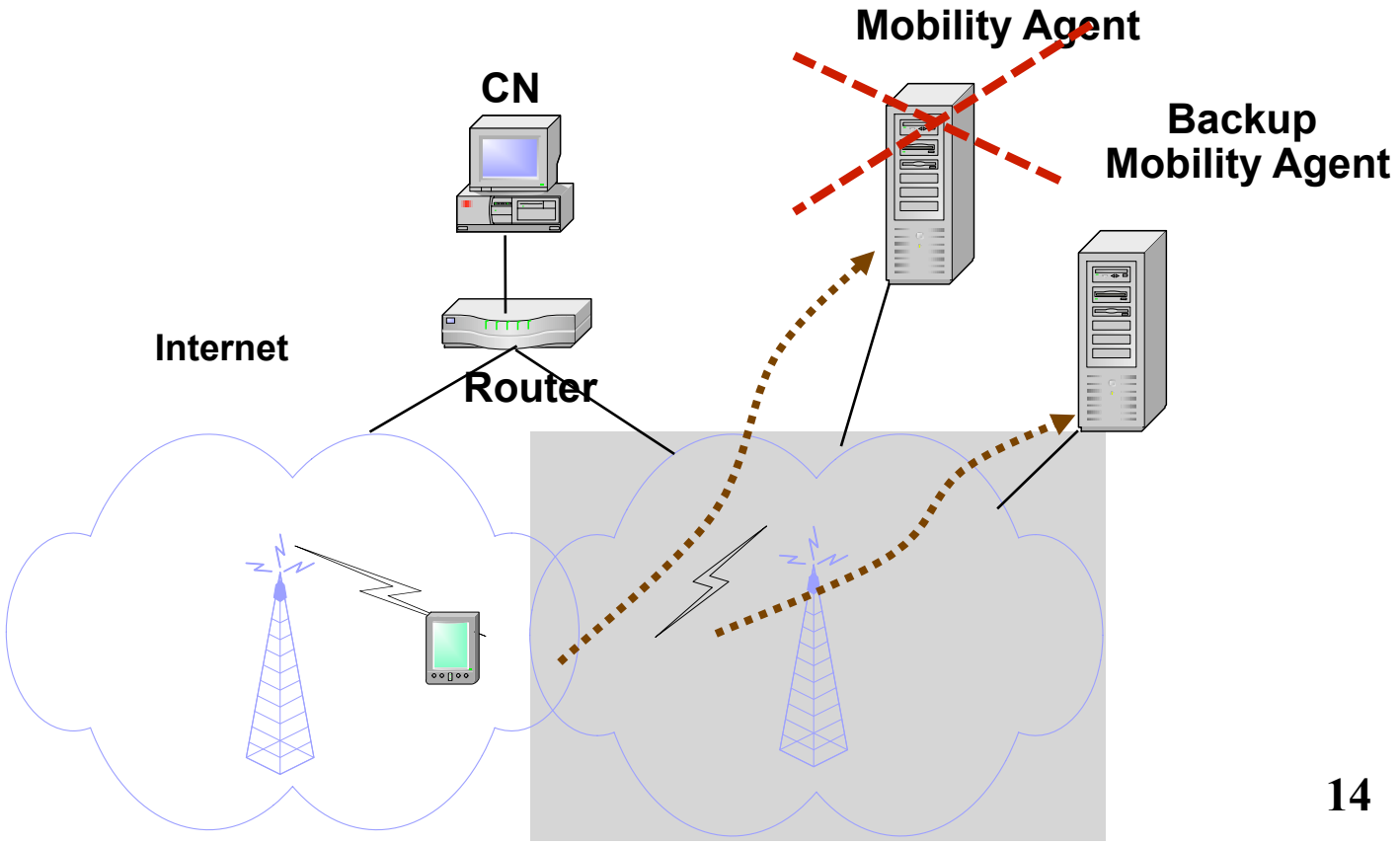
Approaches to improve survivability and scalability

- Redundancy based schemes
- Load balancing schemes
- Removal of FA
- Using Location Register
- Hierarchical approach
- Refresh-based schemes
- DNS as mobility agent

- Quantitative evaluation of survivability and scalability

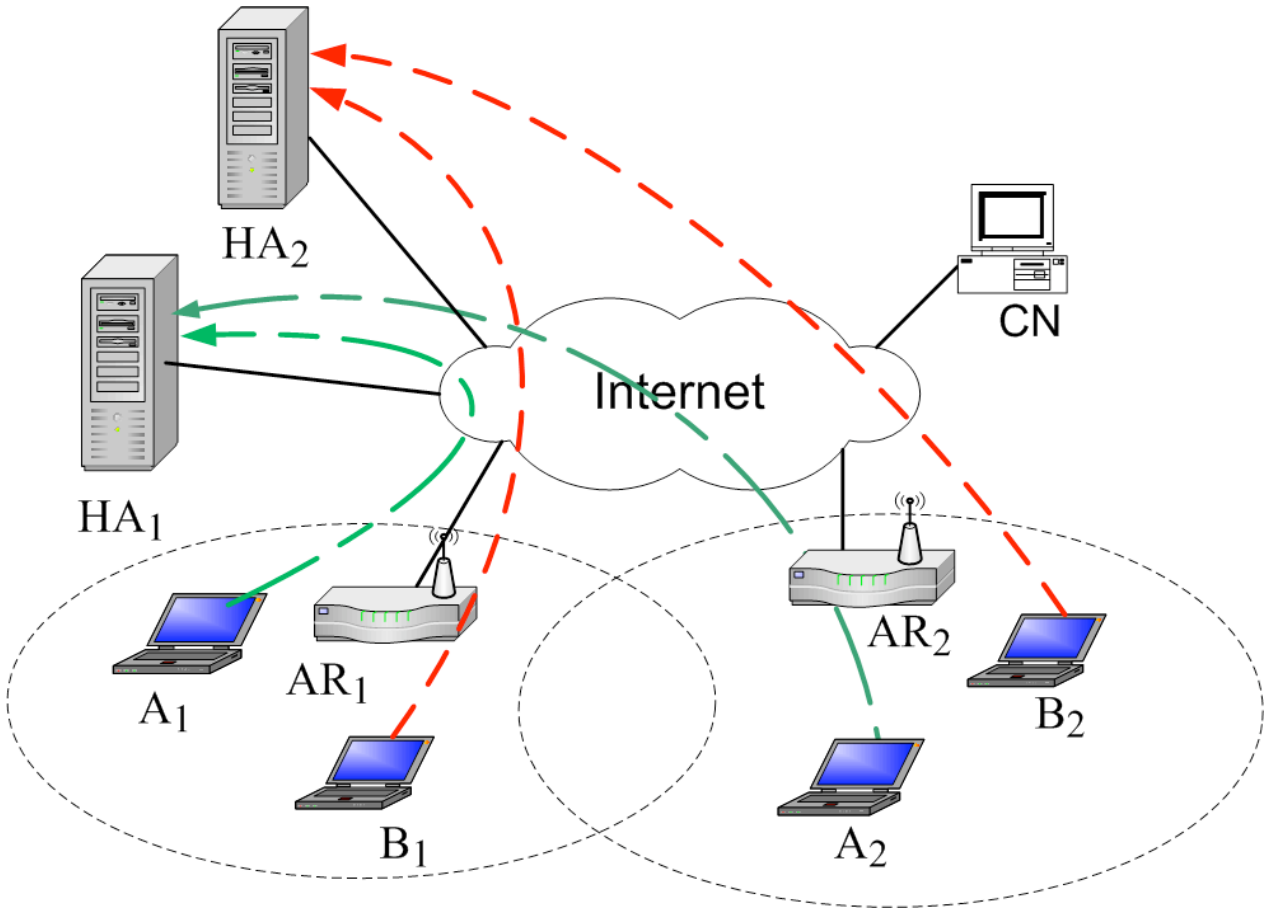
Redundancy based schemes

- Replication of Mobility Agents to have more reliability in case of failure.



Load Balancing schemes

- Load of the mobility agents distributed among multiple agents.

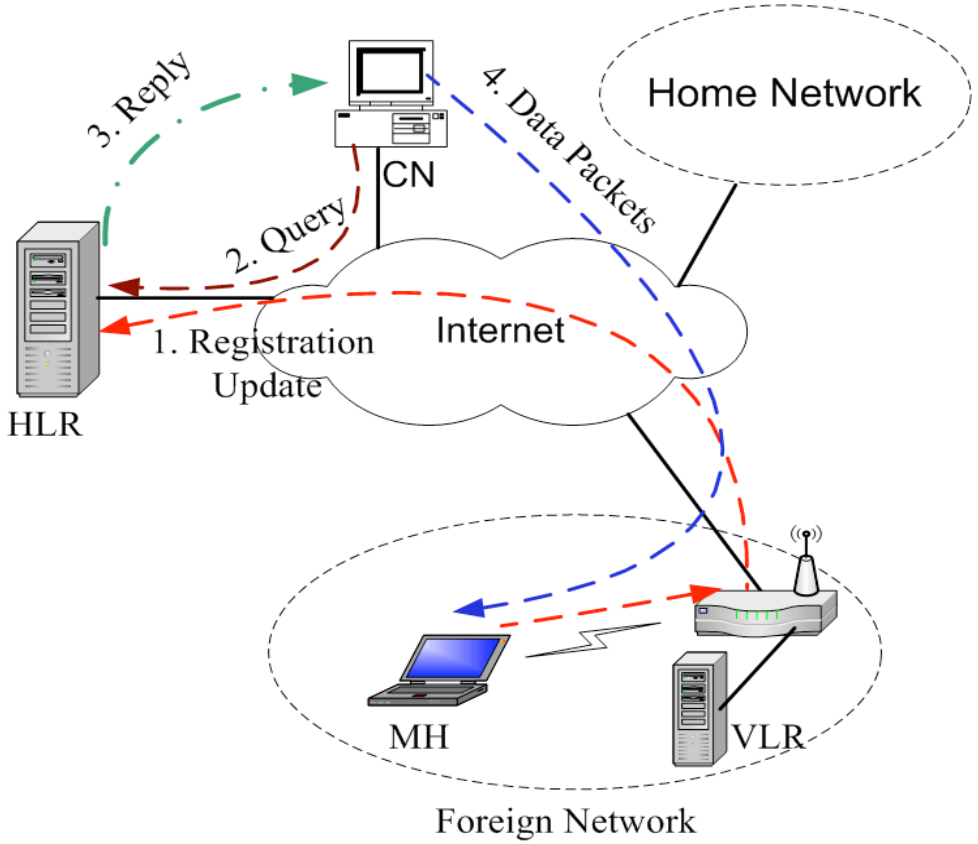


Removal of FA

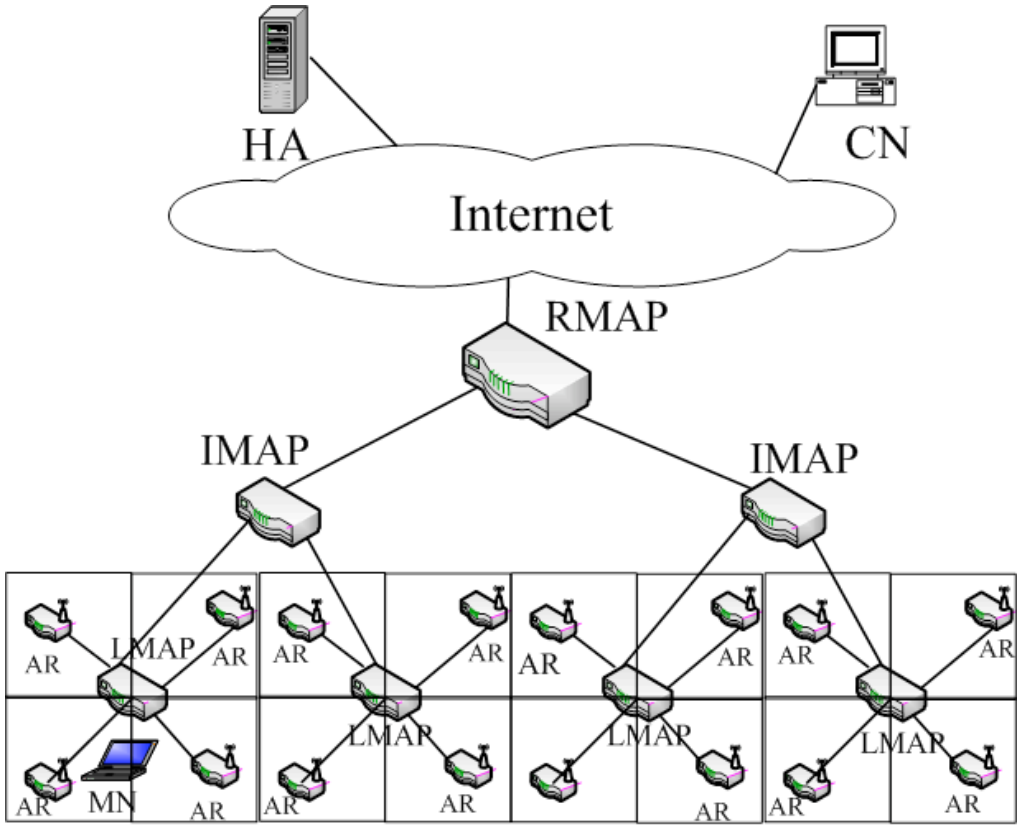
- Foreign Agent are removed to increase scalability and survivability
- Mobile Host has to dynamically acquire IP address.
  - Use DHCP or SAA in IPv6.

Using Location register

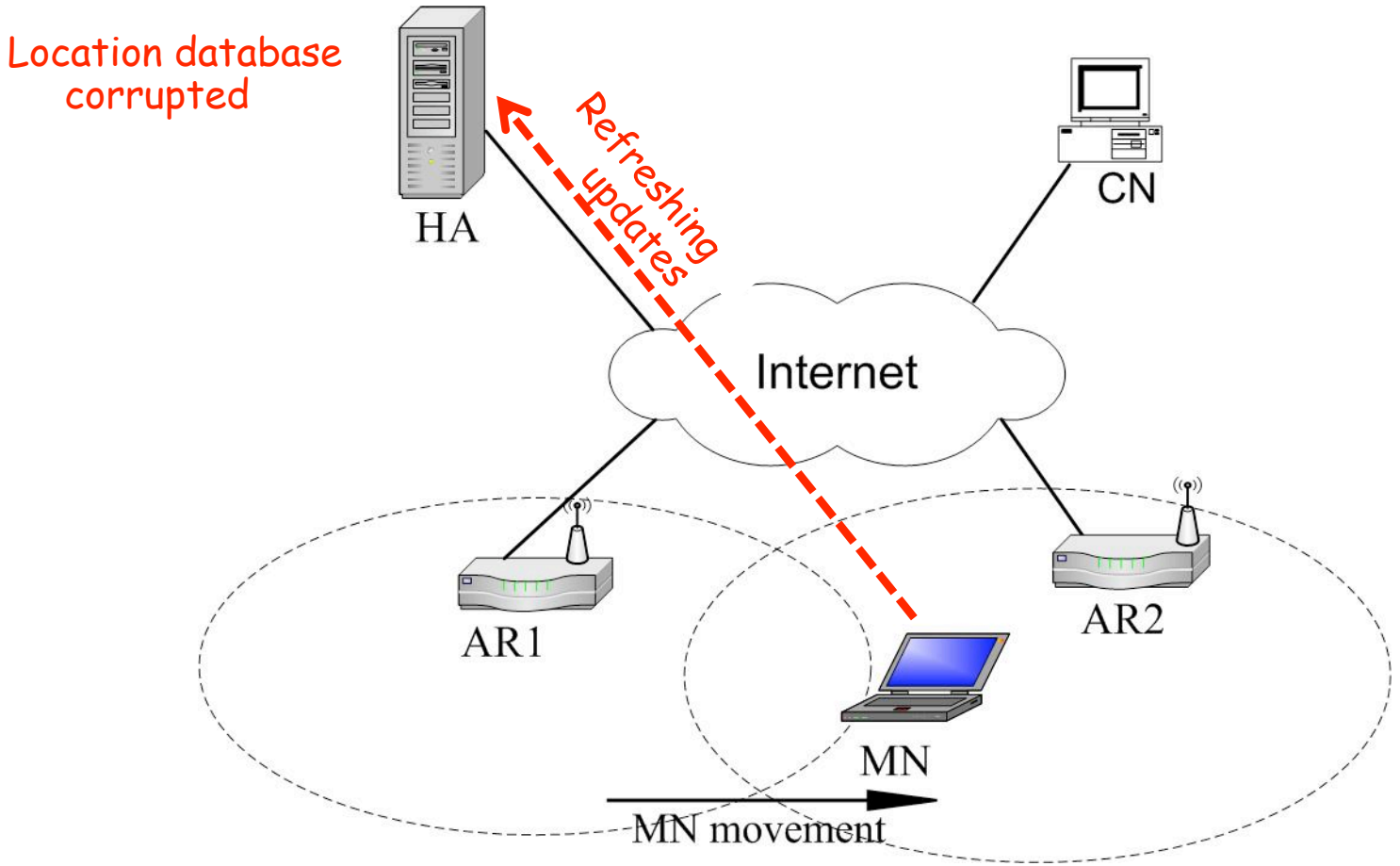
- Location database are very crucial and should not be kept in a vulnerable environment, rather they should be replicated and distributed.
- MIP-LR (Mobile IP with Location Register) places the mobility database outside a vulnerable home network



- Reduce signaling on mobility agents by hierarchical mobility agents.
  - Ÿ Facilitates scalable services as number of mobile nodes increases.
- Examples: Hierarchical Mobile IPv6 (HMIPv6), Robust HMIPv6, Fast HMIPv6, Optimal Multi-level HMIPv6 (OM-HMIPv6)

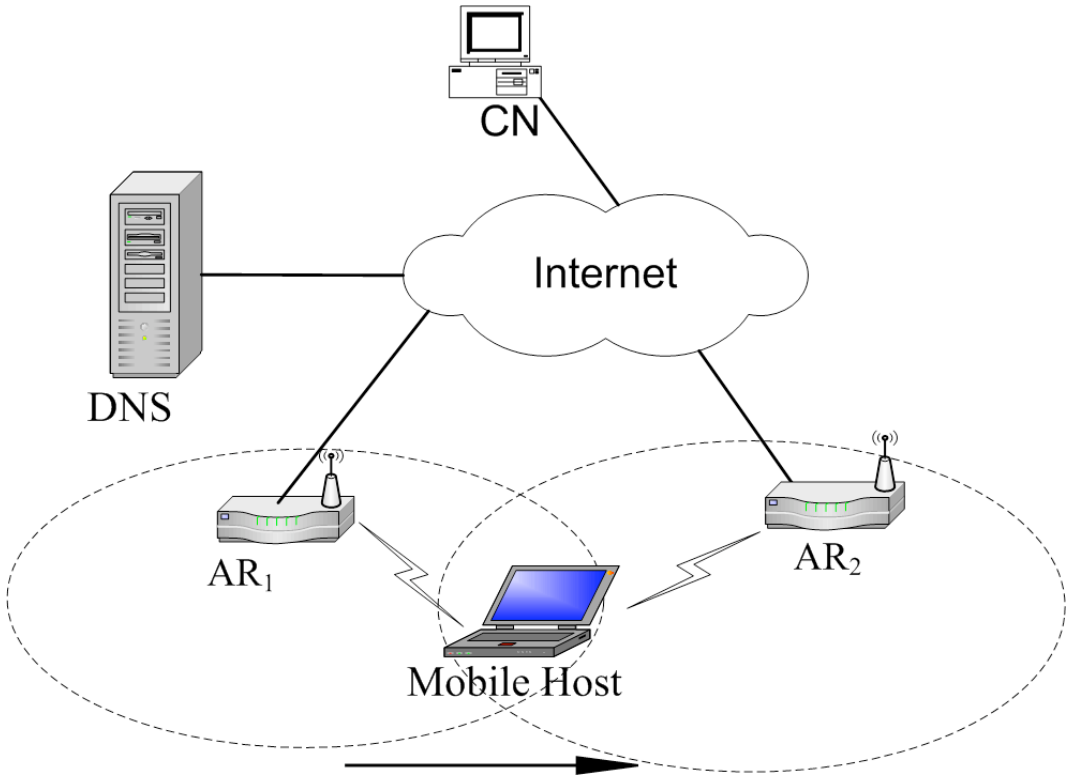


- Mobility database may be damaged, corrupted or lost, rather than the HA itself.
- Can be fixed by sending periodical (refreshing) binding updates.



DNS as mobility agent

- Having home agent in the home network may lead to survivability issues.
  - MHs belonging to a home network are inaccessible if home network is destroyed.
- Mobility agents arranged like DNS structure or can be combined with a DNS server, as in SIGMA.



Quantitative evaluation

- Focus on defining certain metrics or functions for quantitative study of terrestrial and space networks.
- Mathematical modeling are also done for survivability and scalability.
- They measure electronic and physical survivability as functions of
  - Ÿ Traffic rate
  - Ÿ Throughput
  - Ÿ Cost of implementation
  - Ÿ Cost of enemy to destroy the network
  - Ÿ Capacity
  - Ÿ Topology structure

Comparison among the schemes

Schemes	Basic Principle	Advantages	Limitations
Redundancy-based	Multiple redundant MAs are used to avoid single point of failure	Less failure time	Synchronization required among the agents
Load-balancing	Loads on MAs are distributed to allow scalable services	Support large number of nodes with less delay and loss	Some control message with state information (such as queue size) need to be exchanged among MAs
FA removal	MN performs the function of FA	reduces changes in Internet infrastructure	More work in MN
Using LR	Location database are kept in distributed LR instead of HA / FA.	Eliminate tunneling and triangular routing, location database are distributed and secured in case of attack	Every CN may be configured with the address of HLR
Hierarchical	Amount of signaling to MAs are reduced by introducing multi-level hierarchy	Less location update cost	More processing due encapsulation and decapsulation in multiple agents
Refresh-based	Damaged mobility database may be restored by periodic refreshing updates	The MAs are not required to be replicated	Additional signaling required. Location database may be invalid for longer period if refreshing period is high
DNS-based	DNS can be used as location database instead of HA in hostile environment	Location database can be kept secured	DNS was not designed to modify too frequently

Challenges in space networks

- Removal of home network
  - Complete home network may be destroyed
- Bandwidth limitation
  - IP-mobility protocols should be designed in such a way that the satellite bandwidth is utilized efficiently
- Propagation delay
  - In case GEO satellites
- Remote diagnosis and repair
  - Improved survivability and manageability
- Constellation design issues and use of IP-diversity
  - Reduce number of handoffs
  - IP-diversity for seamless connection

Conclusion

- Demonstration of SIGMA and NEMO in space networks.
- Implementation of the Saratoga protocol in ns-2 simulator.
- Testing of mobility protocols using Saratoga
- Survivability and scalability issues for mobility protocols

Thanks to NASA ESTO for funding of this research