MobilityFirst Future Internet Architecture

Yanyong Zhang
WINLAB, Rutgers University
yyzhang@winlab.rutgers.edu

Introduction – A Few Current Trends

Introduction: NSF Future Internet Architecture (FIA) Program

- **FIA program started in Oct 2010, with 5 teams funded:**
  - XIA (led by CMU) – project aims to develop very flexible architecture which can evolve to meet new requirements
  - NEBULA (led by UPenn) – project aims to design fast/managed flows to cloud services at the core of the Internet
  - NDN (led by UCLA/PARC) – project aims to re-design Internet to handle named content efficiently
  - ChoiceNet (led by RENCI/UNC) – project aims to enable choice and competition at each layer of protocol stack
  - **MobilityFirst** (led by Rutgers) – project aims to develop efficient and scalable architecture for emerging mobility services
- Scope of all these FIA projects includes architecture/design, protocol validation and comprehensive evaluation of usability and performance (using real-world applications in later stages)

MobilityFirst Project: Collaborating Institutions

RUTGERS (LEAD)

D. Raychaudhuri, M. Gruteser, W. Trappe,
R, Martin, Y. Zhang, I. Seskar,
K. Nagaraja

A. Venkataramani, J. Kurose, D. Towsley

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

M. Reiter

THE UNIVERSITY of WISCONSIN MADISON

S. Bannerjee

Massachusetts Institute of Technology

W. Lehr

MICHIGAN

Z. Morley Mao

Duke UNIVERSITY

X. Yang, R. RoyChowdhury

UMASS LOWELL

G. Chen

UNIVERSITY OF Nebraska Lincoln

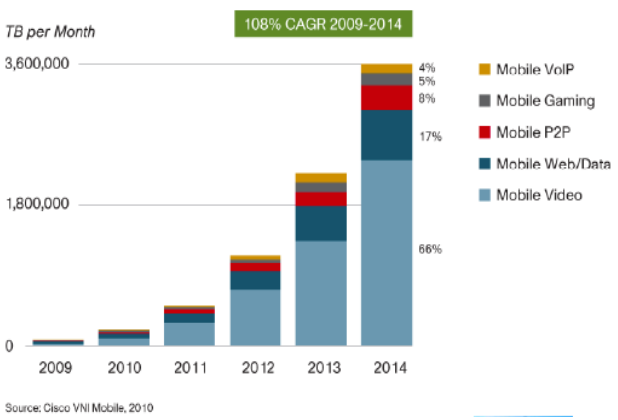
B. Ramamurthy

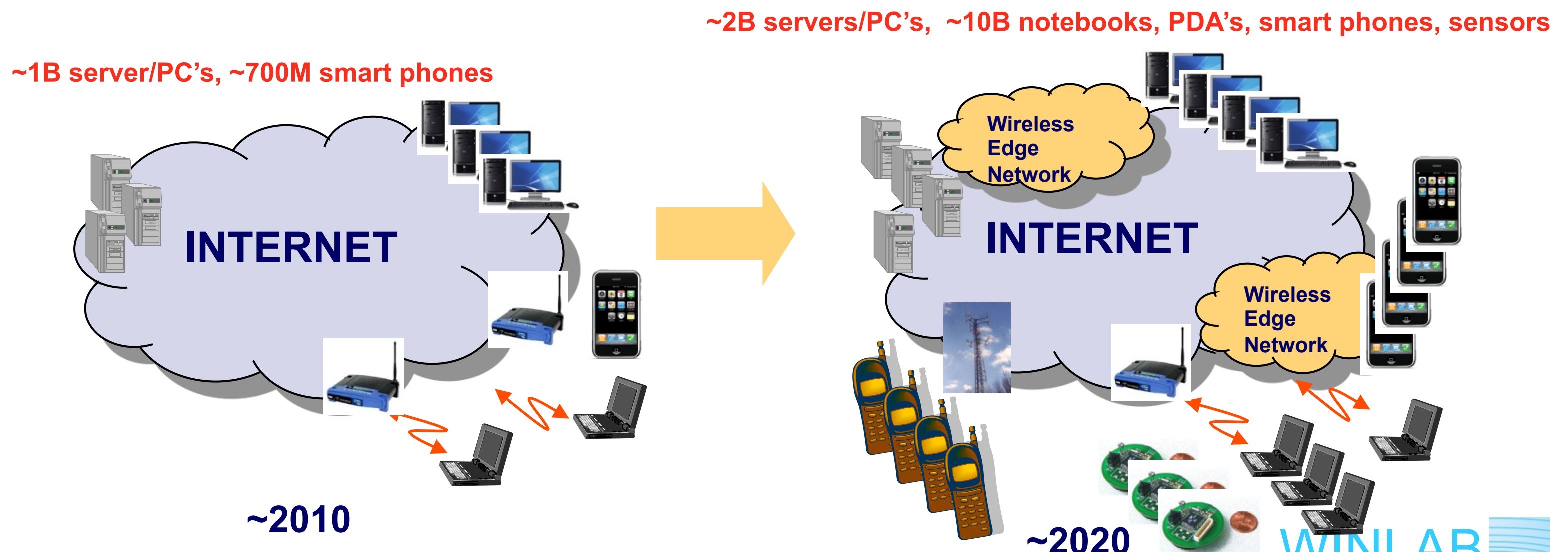
+ Also industrial R&D collaborations with AT&T Labs,
Bell Labs, NTT DoCoMo,, Toyota ITC, NEC, Ericsson and others

Project Funded by the US National Science Foundation (NSF)
Under the Future Internet Architecture (FIA) Program, CISE

Introduction: Mobility as *the* key driver for the future Internet

- Historic shift from PC's to mobile computing and embedded devices…
  - ~4 B cell phones vs. ~1B PC's in 2010
  - Mobile data growing exponentially – Cisco white paper predicts 3.6 Exabytes by 2014, significantly exceeding wired Internet traffic
  - Sensor/IoT/V2V just starting, ~5-10B units by 2020



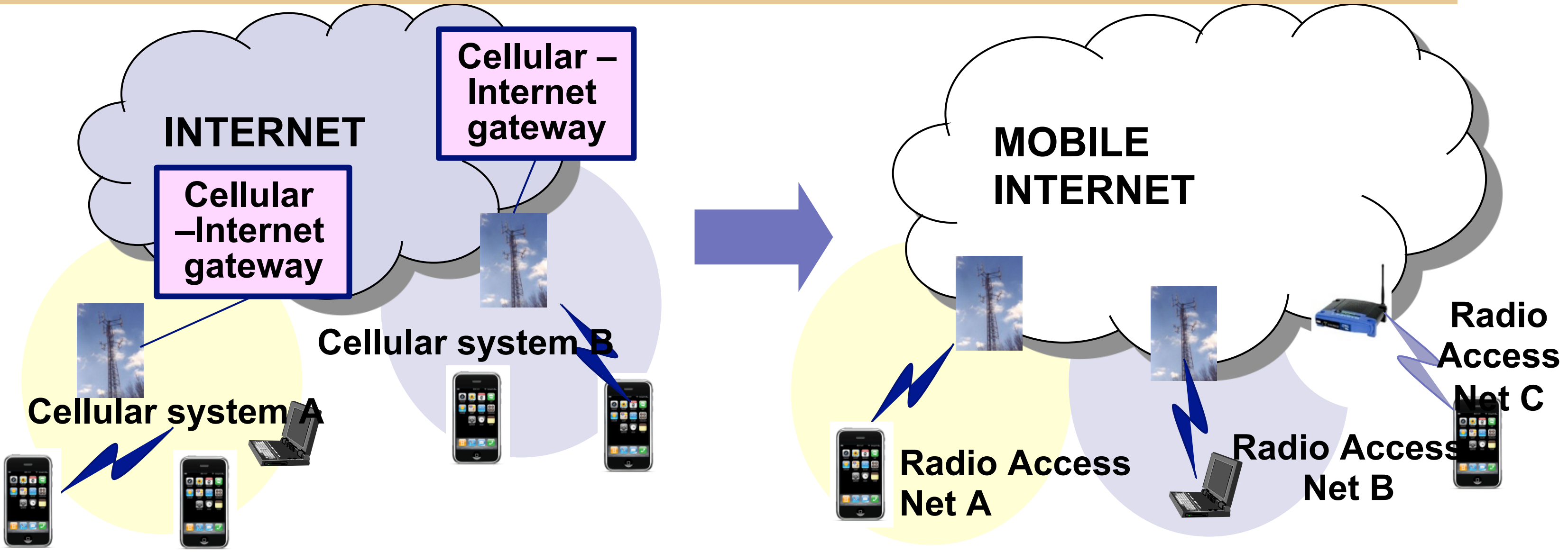


WINLAB

Introduction: Cellular-Internet convergence

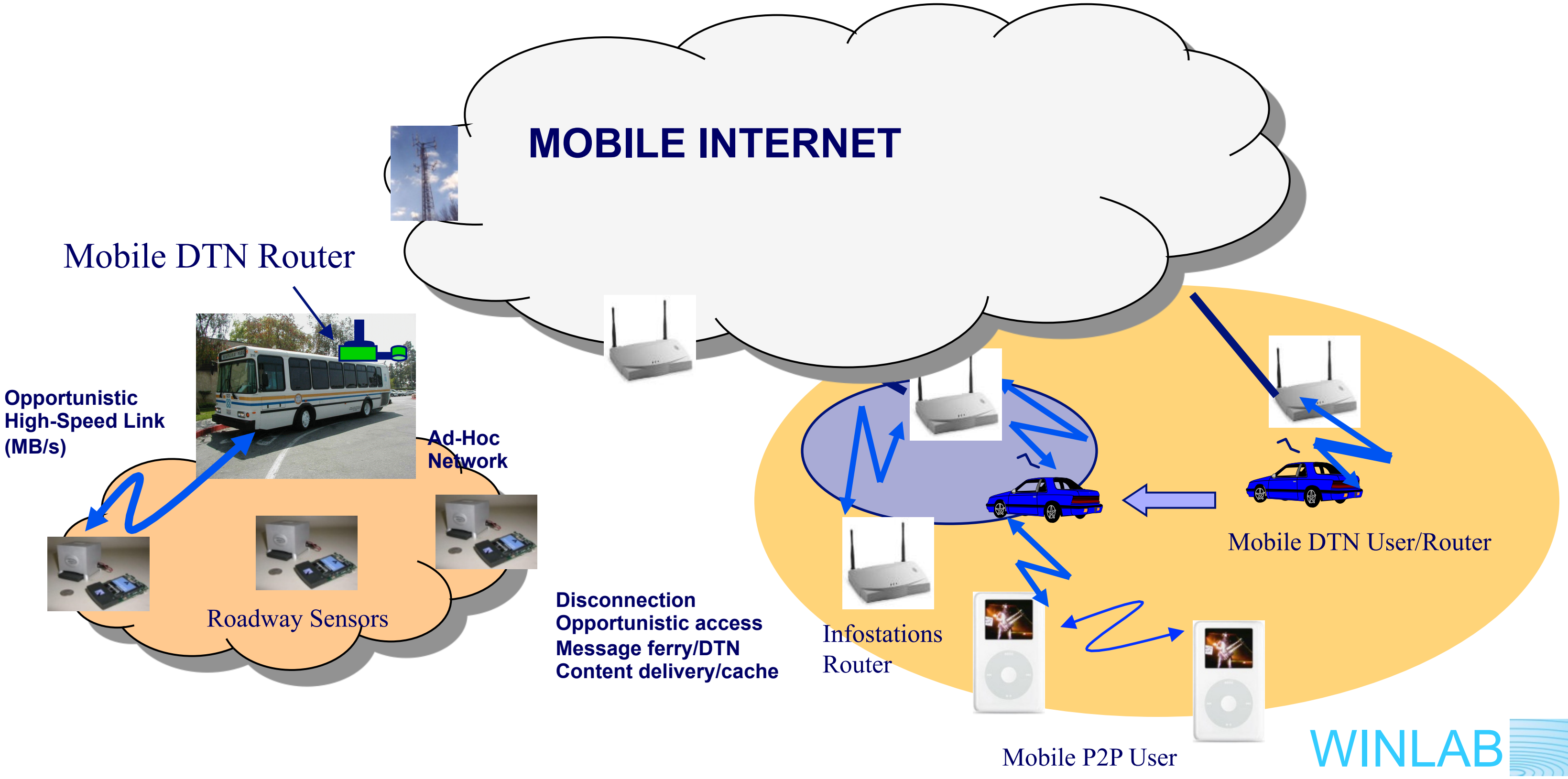
- Technology disparity today
  - Two sets of addresses (cell number & IP), protocols (3GPP, IP), and protocol gateways (GGSN)
  - Poor scalability, fragile, difficult to manage
  - More complications with heterogeneous radio access

Single unified architecture can simplify and speed up mobile Internet application development across diverse networks and platforms



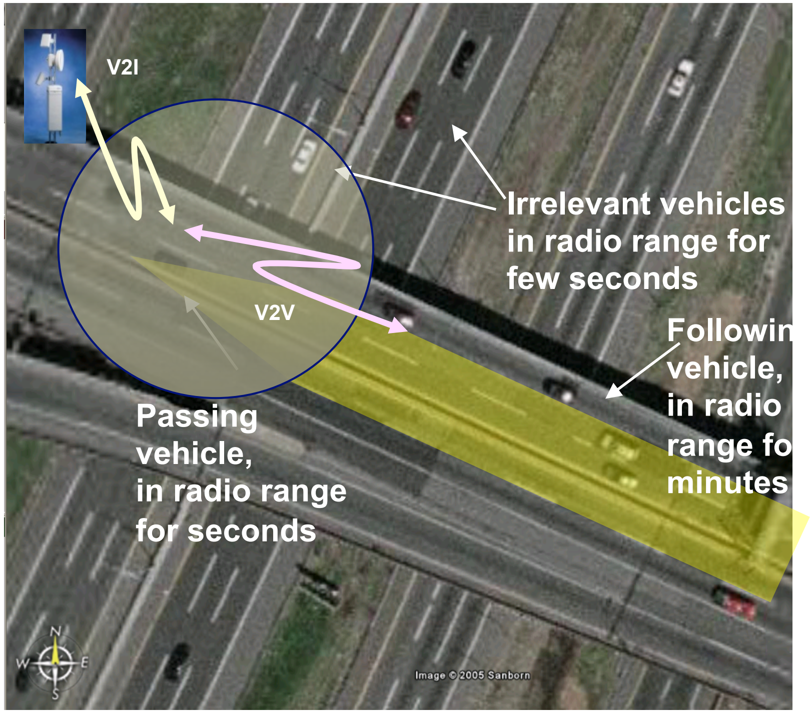
Introduction: Opportunistic Content Delivery

- Opportunistic, delay tolerant (DTN-type) delivery modes and content caching increasingly important for mobile devices
  - Heterogeneous access; network may be disconnected at times
  - Significant performance gain via content caching and opportunistic delivery
  - P2P mode of content delivery can also play a useful role …



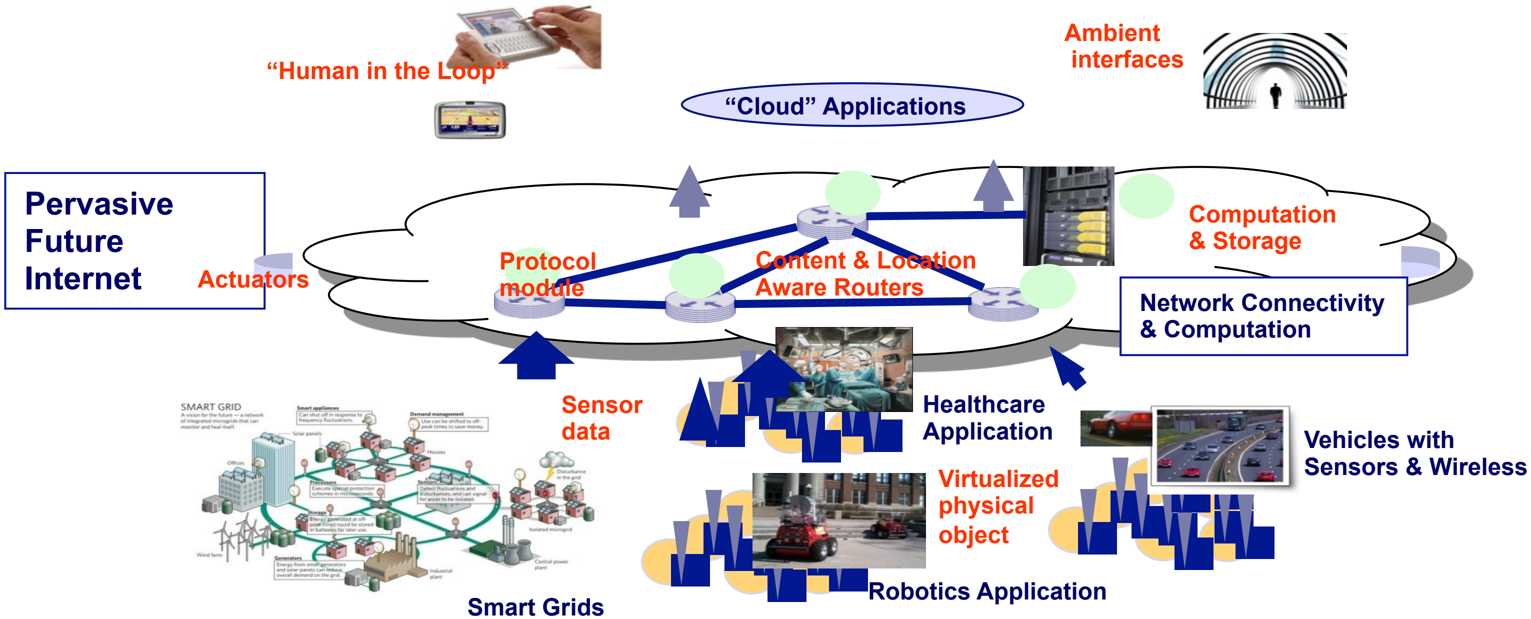
Introduction: Vehicular Networks

- 100's of millions of cars with radios by ~2015
  - Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) modes
  - Support for dynamic network formation, network mobility, geo-routing, etc.
  - Critical new security and privacy requirements



Introduction: Pervasive Cyber-Physical Systems/Internet-of-Things (IoT)

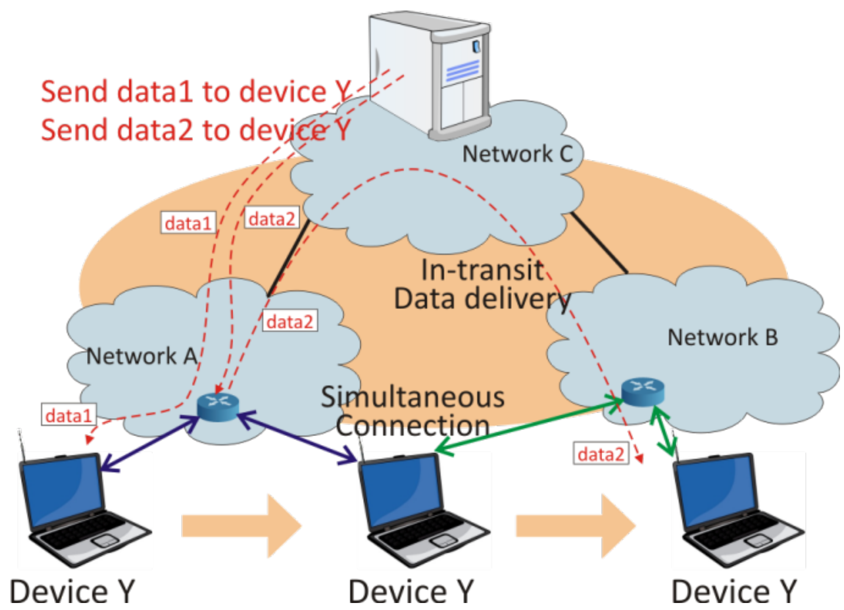
- Next-generation Internet applications will interface human beings with the physical world, e.g.,
  - Machine-to-machine (M2M), cyber-physical systems, smart grids, ..
  - Location and context-aware embedded computing
  - Secure and flexible network computing ('edge cloud") model



Wireless Access Considerations

Wireless Access Considerations:
Supporting Mobility as Basic Service

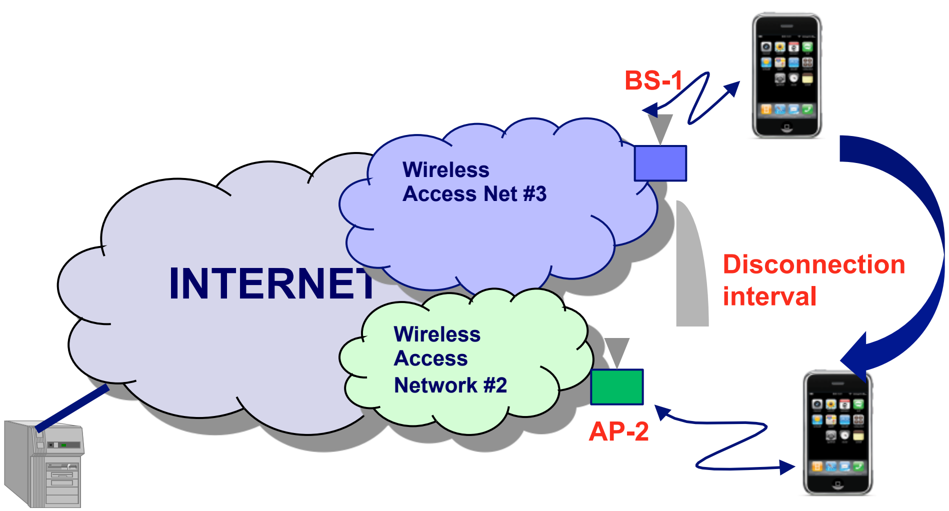
- End-point mobility as a basic service of the future Internet
  - Any network connected object or device should be reachable as it migrates from one network to another
  - Requirements similar to mobile IP in the Internet today and dynamic handoff/ roaming in cellular networks
  - Mobility service should be scalable (billions of devices) and fast ~50-100 ms

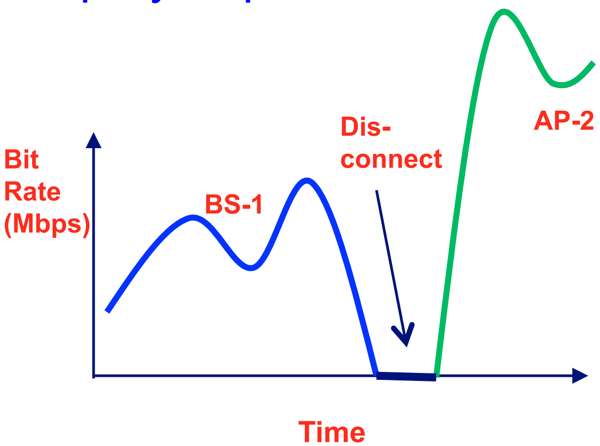


Wireless Access Considerations: Handling BW Variation & Disconnection

- Wireless medium has inherent fluctuations in bit-rate (as much as 10:1 in 3G/4G access), heterogeneity and disconnection
  - Poses a fundamental protocol design challenge
  - New requirements include in-network storage/delay tolerant delivery, dynamic rerouting (late binding), etc.
  - Transport layer implications → end-to-end TCP vs. hop-by-hop

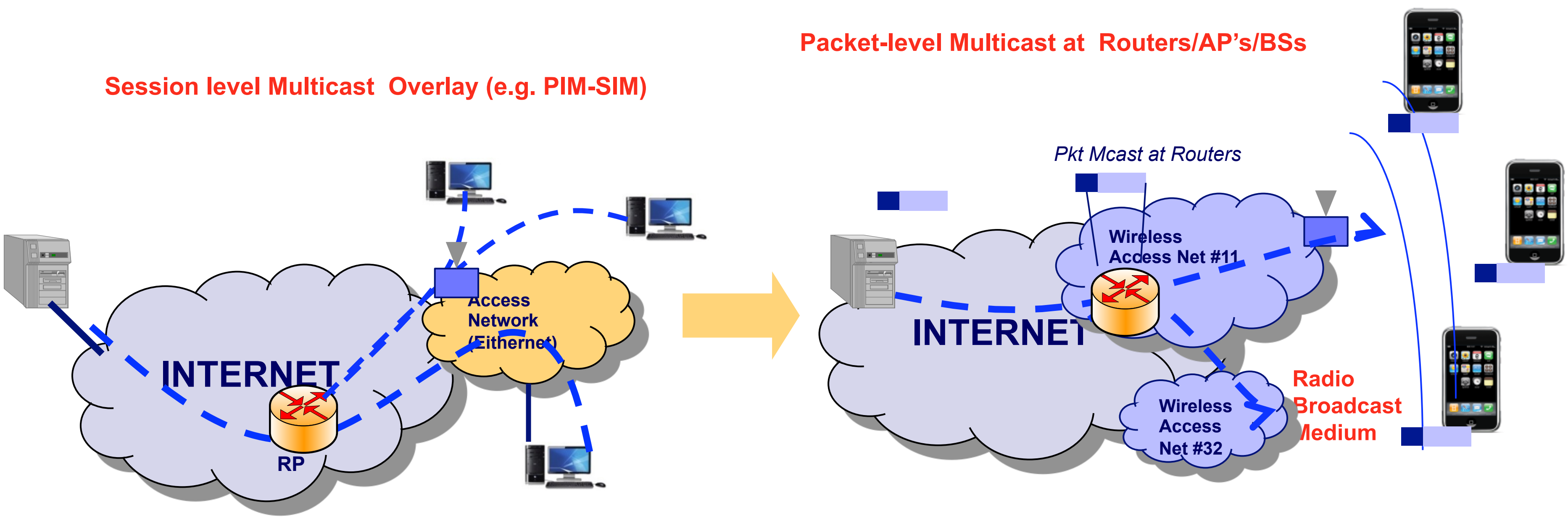
Mobile devices with varying BW due to SNR variation,
Shared media access and heterogeneous technologies





Wireless Access Considerations: Multicast as a Basic Network Service

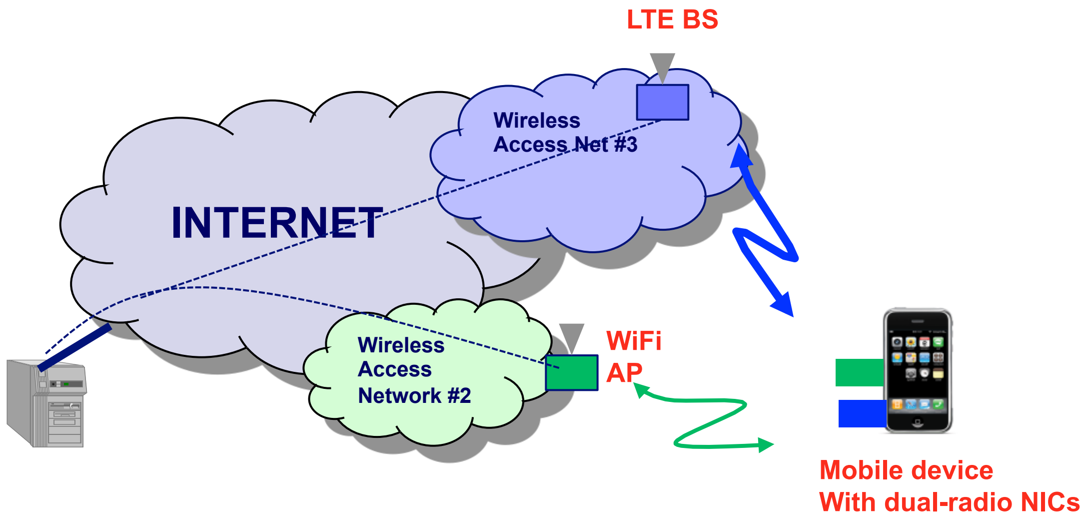
- Many mobility services (content, context) involve multicast
- The wireless medium is inherently multicast, making it possible to reach multiple end-user devices with a single transmission
- Fine-grain packet level multicast desirable at network routers



Wireless Access Considerations:
Multi-Homing as a Standard Service

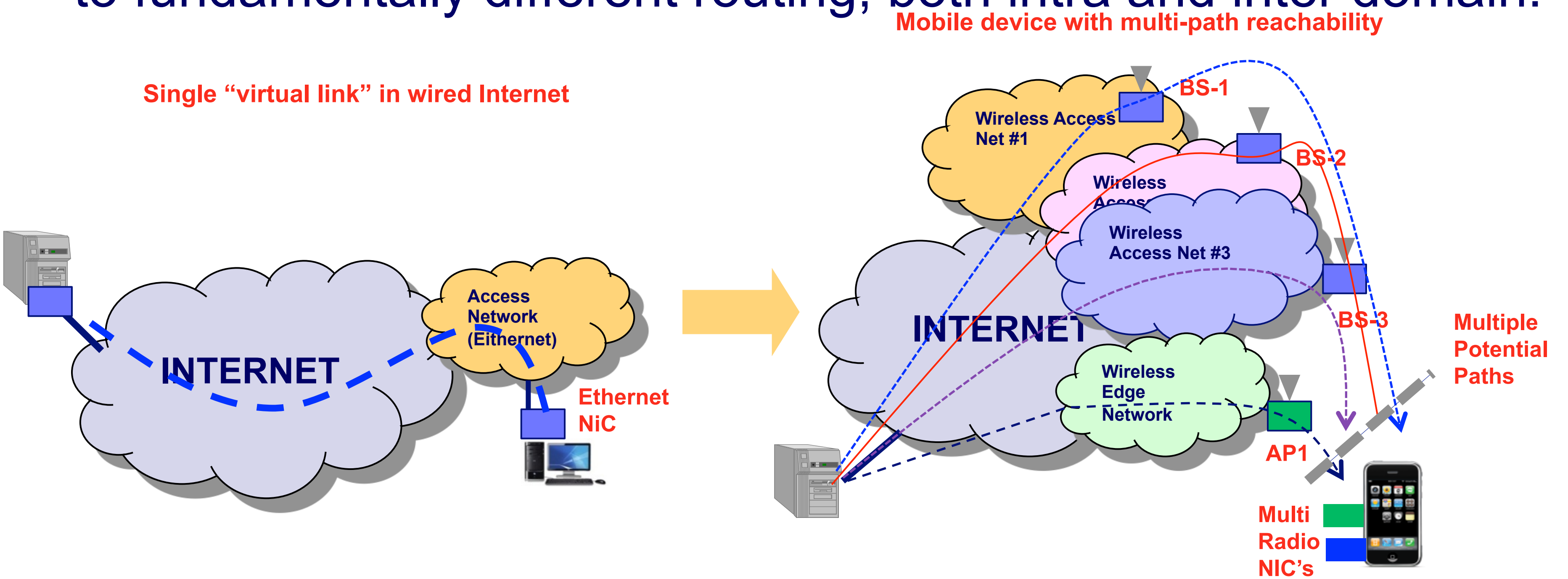
- Multiple/heterogeneous radio access technologies (e.g. 3G/4G and WiFi) increasingly the norm
  - Implies the need for separating “identity” from “locators” (network addresses)
  - Requires routing framework that supports packet level multicasting where needed for efficient delivery to multiple networks
  - Support for alternative routing policies – “best path”, “all paths”, etc.

Multihomed devices may utilize two or more interfaces to improve communications quality/cost, with policies such as “deliver on best interface” or “deliver only on WiFi”



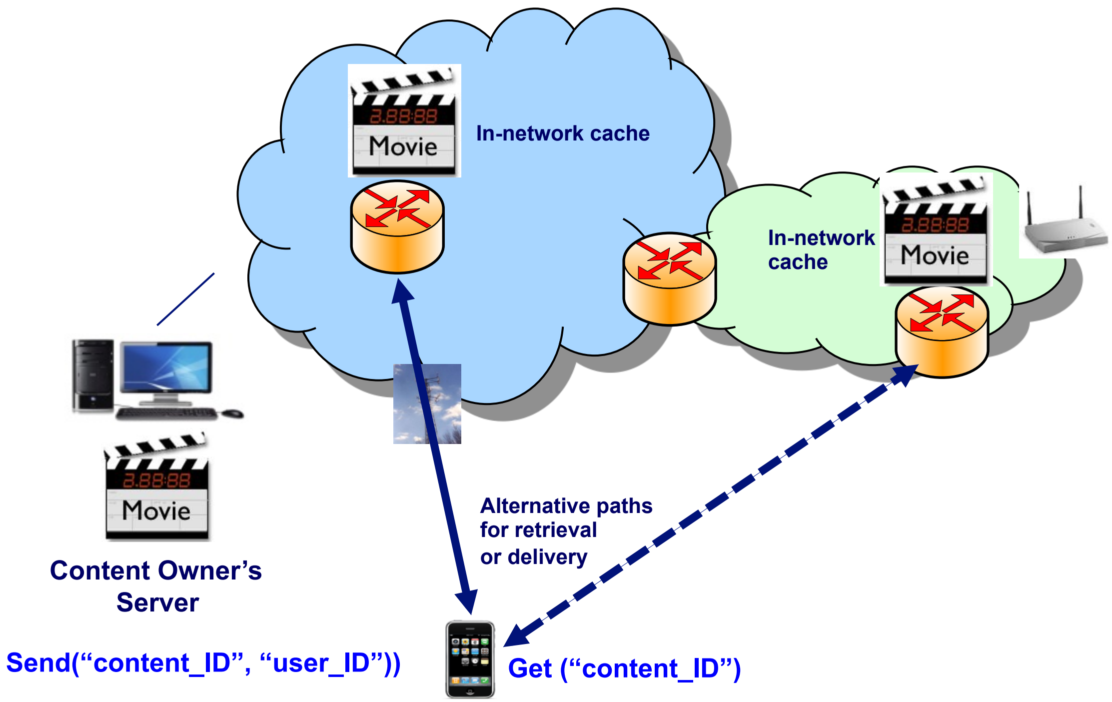
Wireless Access Considerations:
Supporting Multi-Network Access, Multipath

- Wired Internet devices typically have a single Ethernet interface associated with a static network/AS
- In contrast, mobile devices typically have ~2-3 radios and can see ~5-10 distinct networks/AS's at any given location
- Basic property - multiple paths to a single destination → leads to fundamentally different routing, both intra and inter domain!



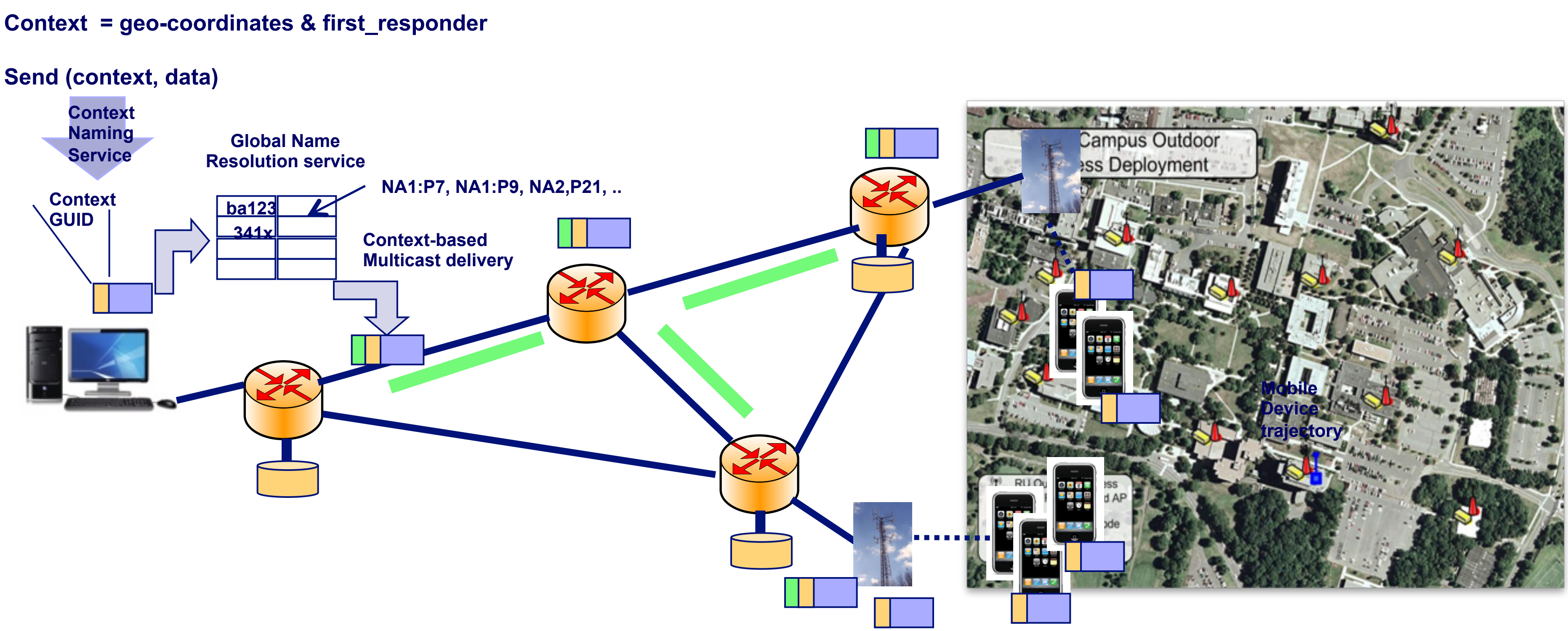
Wireless Access Considerations: Content Retrieval & Delivery Capabilities

- Delivery of content to/from mobile devices is a key service requirement in future networks
- This requirement currently served by overlay CDN's
- In-network support for content addressability and caching is desirable → service primitives such as *get(content-ID, ..)*



Wireless Access Considerations: Supporting Context-Aware Services

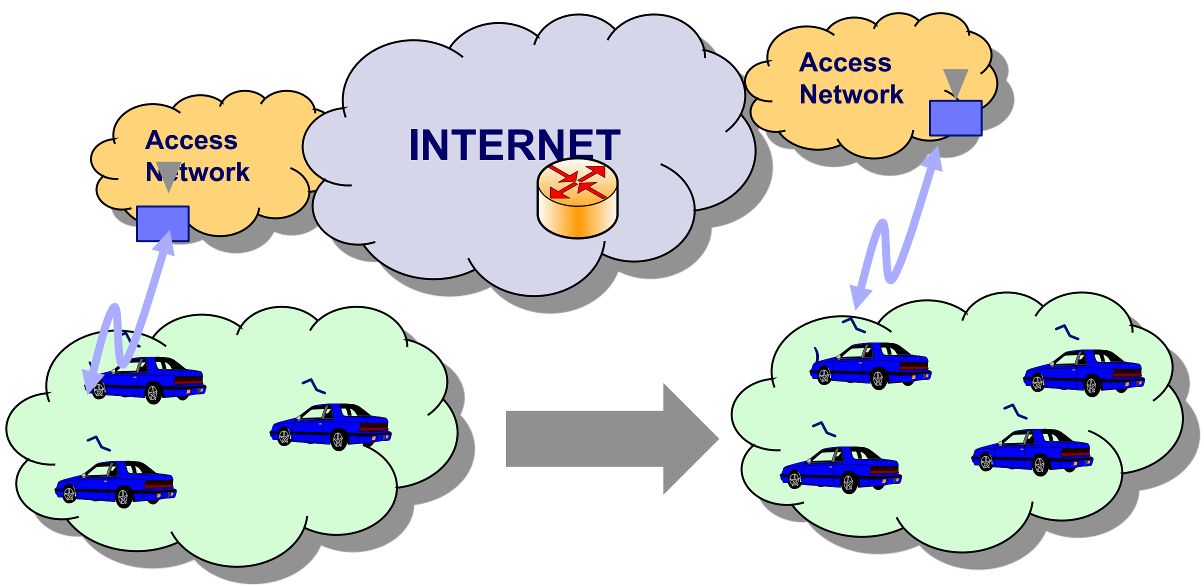
- Context-aware delivery often associated with mobile services
  - Examples of context are group membership, location, network state, …
  - Requires framework for defining and addressing context (e.g. "taxis in New Brunswick")
  - Anycast and multicast services for message delivery to dynamic group



Wireless Access Considerations: Ad Hoc & Network Mobility

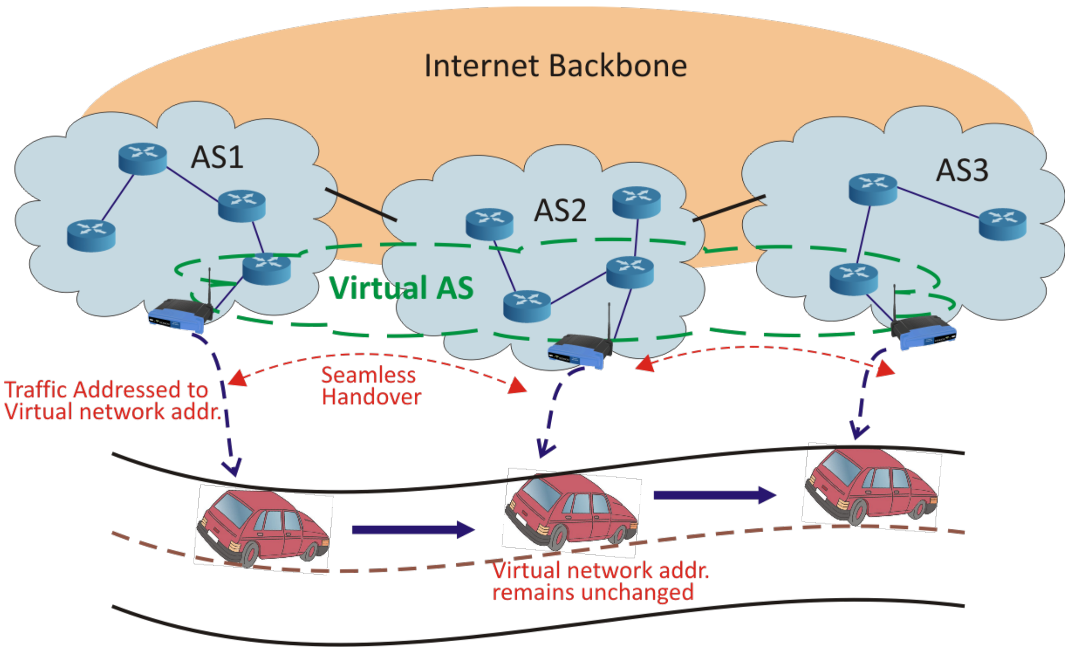
- Wireless devices can form ad hoc networks with or without connectivity to the core Internet
- These ad hoc networks may also be mobile and may be capable of peering
- Requires rethinking of interdomain routing, trust model, etc.

Ad Hoc Network Formation, Intermittent Connection to Wired Internet & Network Mobility



Wireless Access Considerations:
Flexible AS Formation

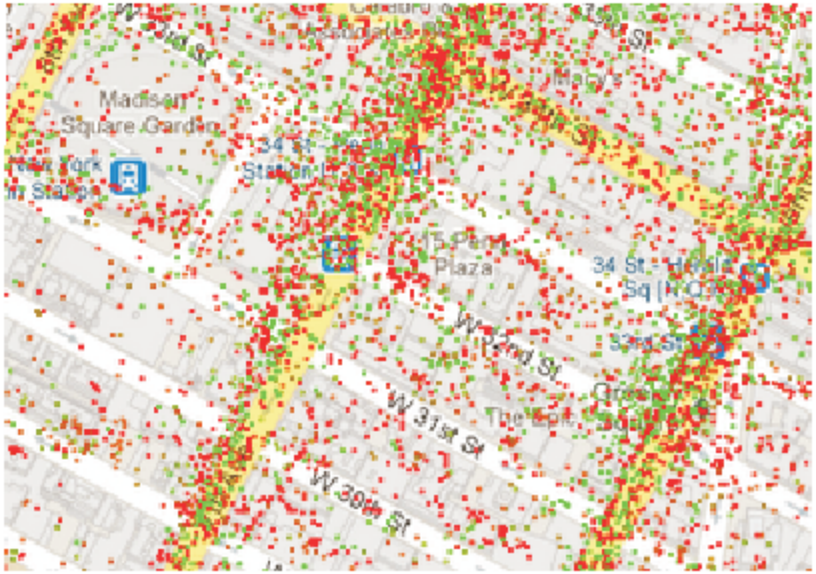
- In contrast to wired Internet, wireless access networks need not be physically contiguous, e.g. free WiFi networks in a region may join to form a single service network
- Also, network mobility implies virtual networks with moving parts under a single network address

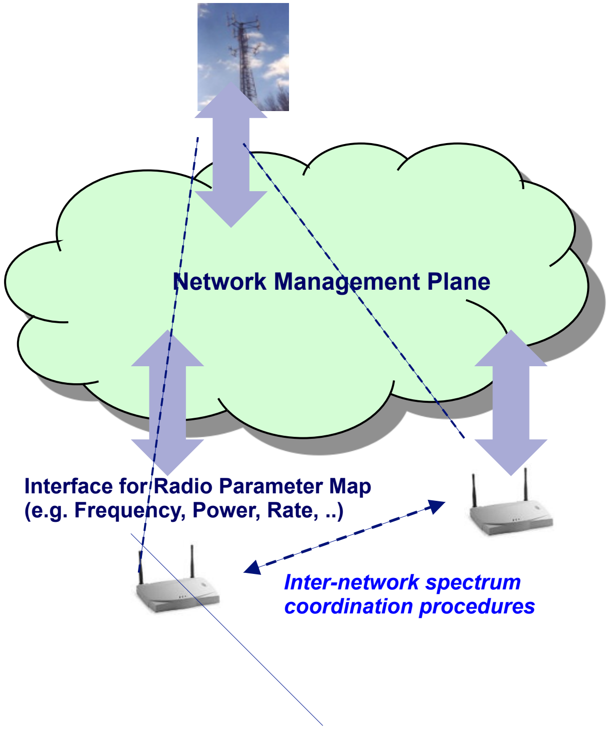


Wireless Access Considerations:
Spectrum Coordination as a Network Service

- As more and more data is carried by unlicensed wireless networks, spectrum coordination should be offered as a network service
- Management plane offers global visibility for cooperative setting of radio resource parameters across independent access networks

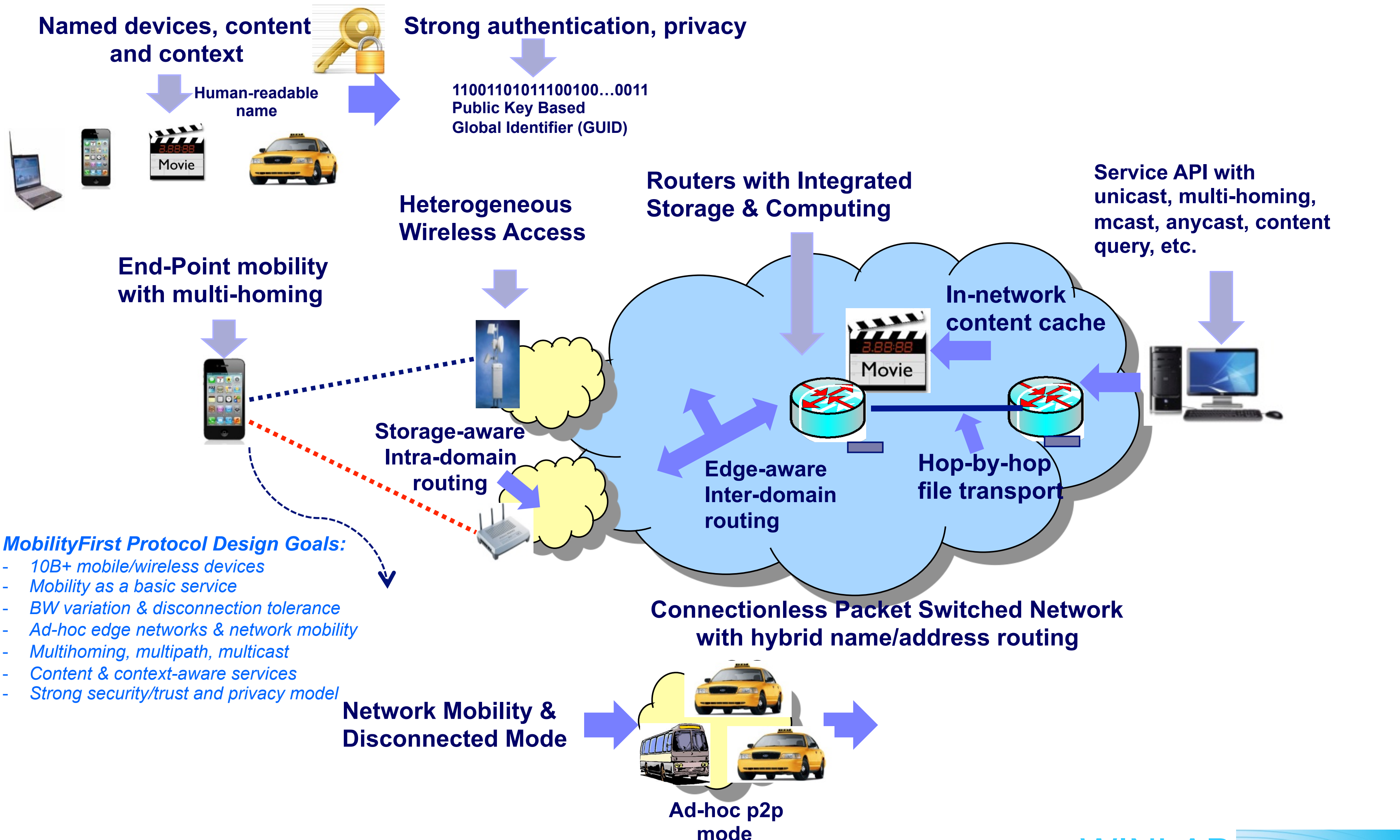
WiFi AP locations in a 0.4x0.5 sq.mile area in Manhattan, NY





MobilityFirst Protocol Design

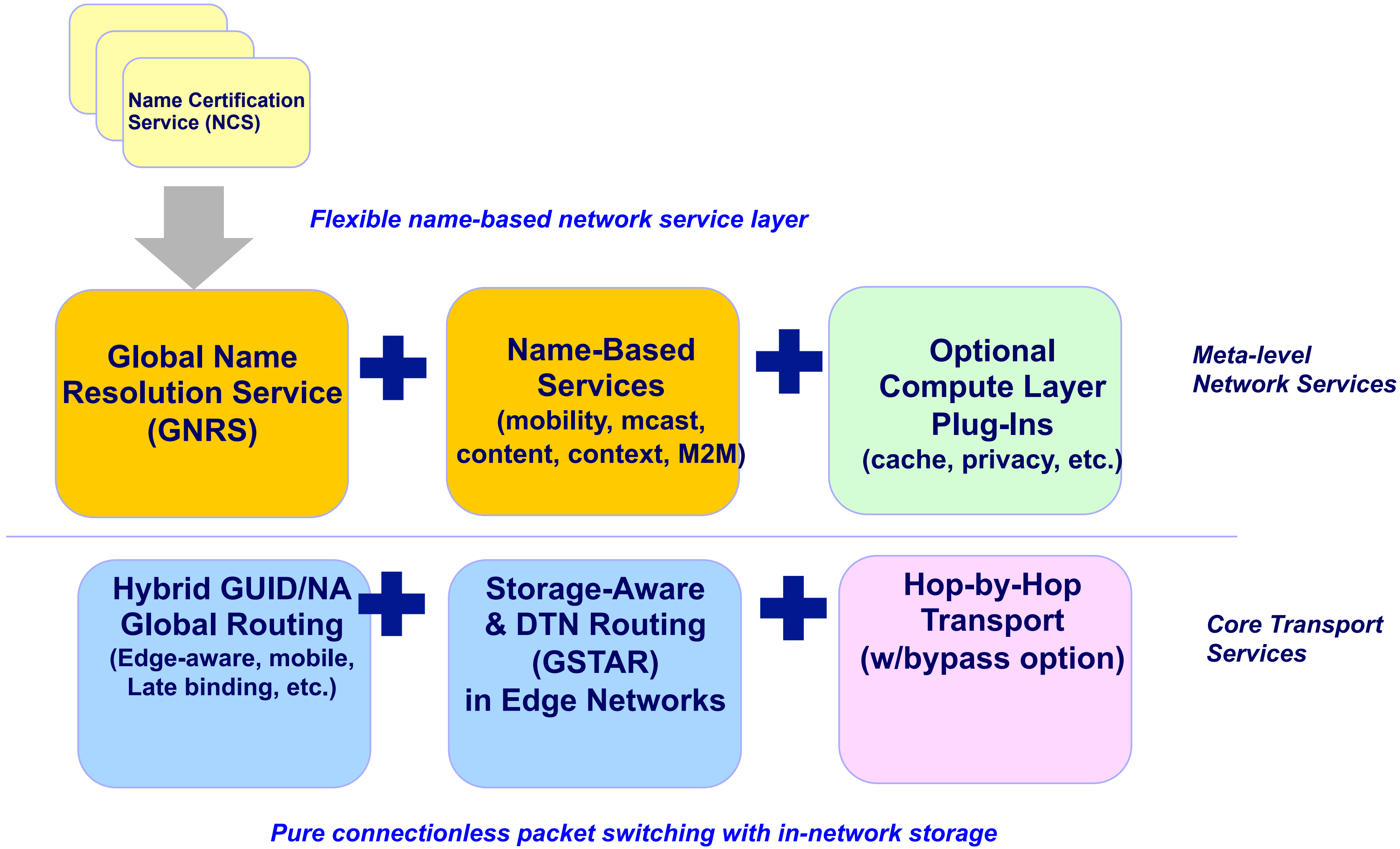
MobilityFirst Design: *Architecture Features*



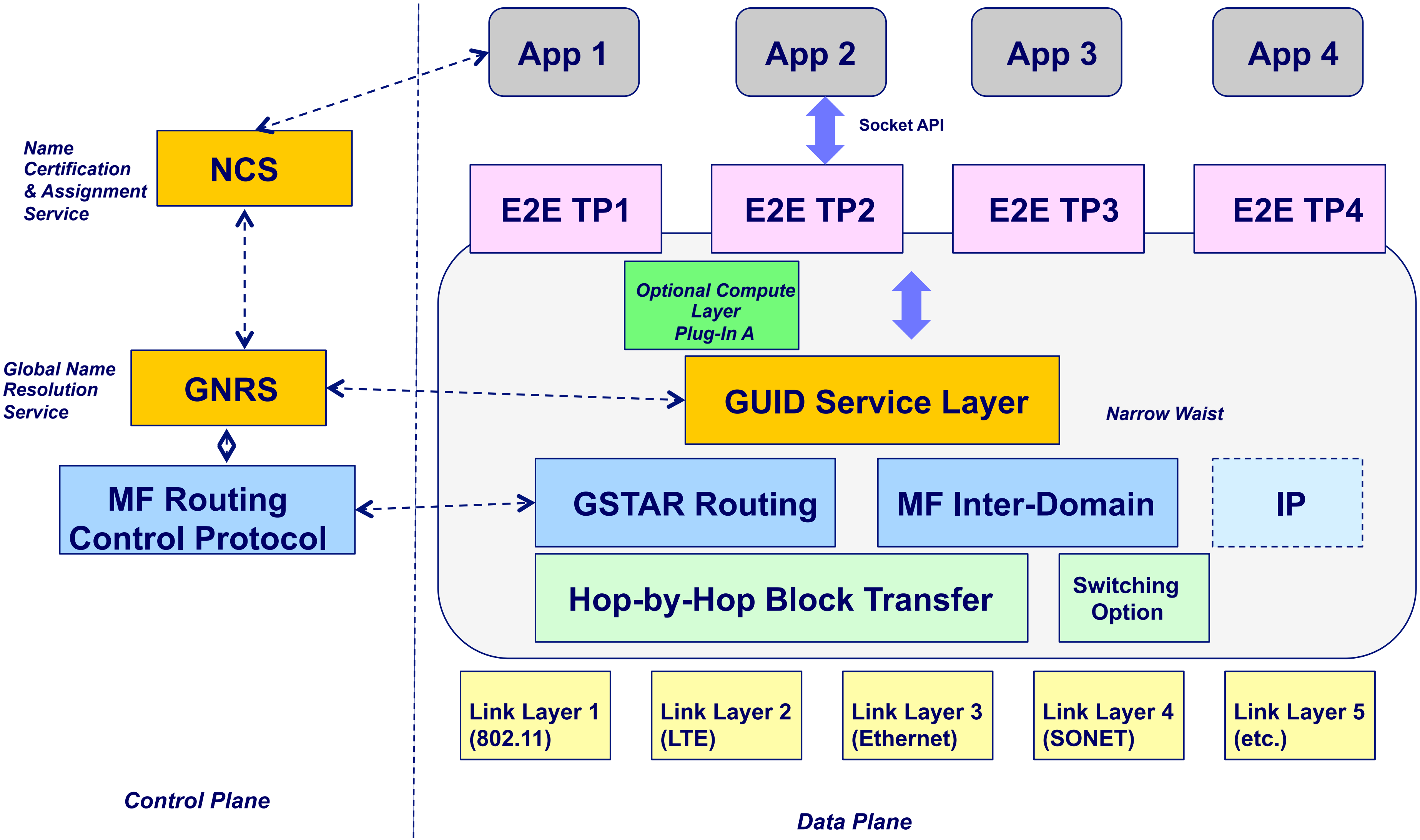
MobilityFirst Protocol Design Goals:

- *10B+ mobile/wireless devices*
- *Mobility as a basic service*
- *BW variation & disconnection tolerance*
- *Ad-hoc edge networks & network mobility*
- *Multihoming, multipath, multicast*
- *Content & context-aware services*
- *Strong security/trust and privacy model*

MobilityFirst Design: *Technology Solution*



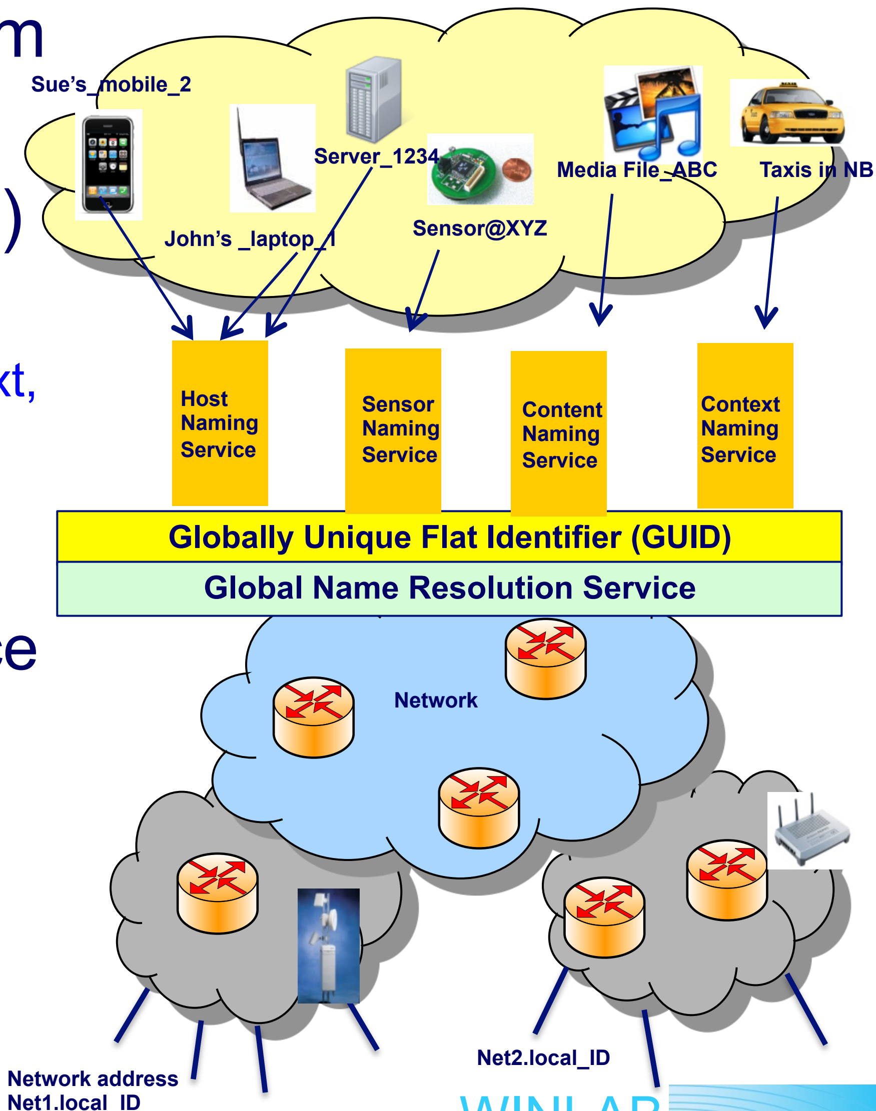
MobilityFirst Design: *Protocol Stack*



WINLAB

Protocol Design: Name-Address Separation → GUIDs

- Separation of names (ID) from network addresses (NA)
- Globally unique name (GUID) for network attached objects
  - User name, device ID, content, context, AS name, and so on
  - Multiple domain-specific naming services
- Global Name Resolution Service for GUID → NA mappings
- Hybrid GUID/NA approach
  - Both name/address headers in PDU
  - "Fast path" when NA is available
  - GUID resolution, late binding option

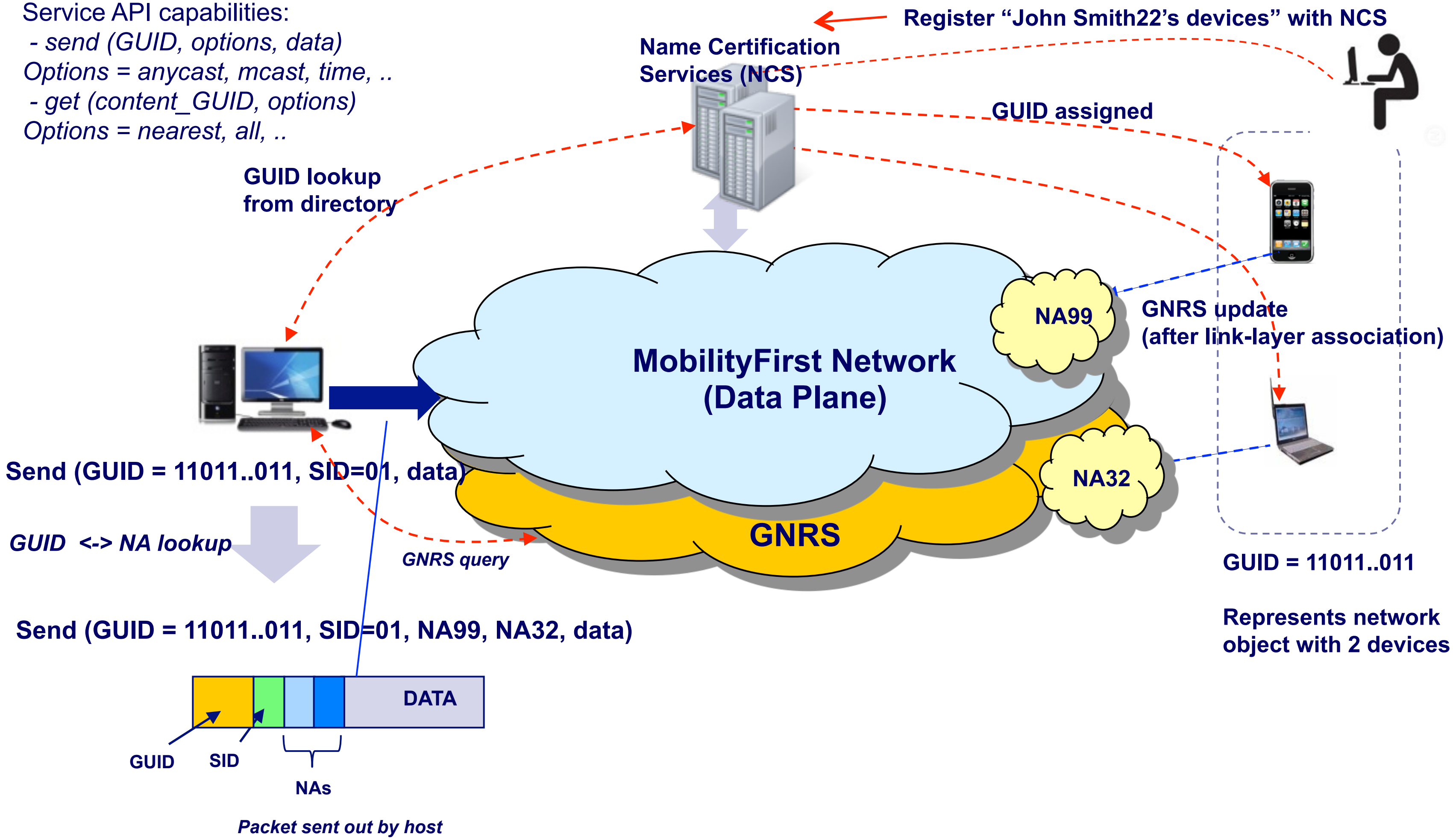


Protocol Example: Mobility Service via Name Resolution at Device End-Points

Service API capabilities:
- *send (GUID, options, data)*

Options = anycast, mcast, time, ..
- *get (content_GUID, options)*

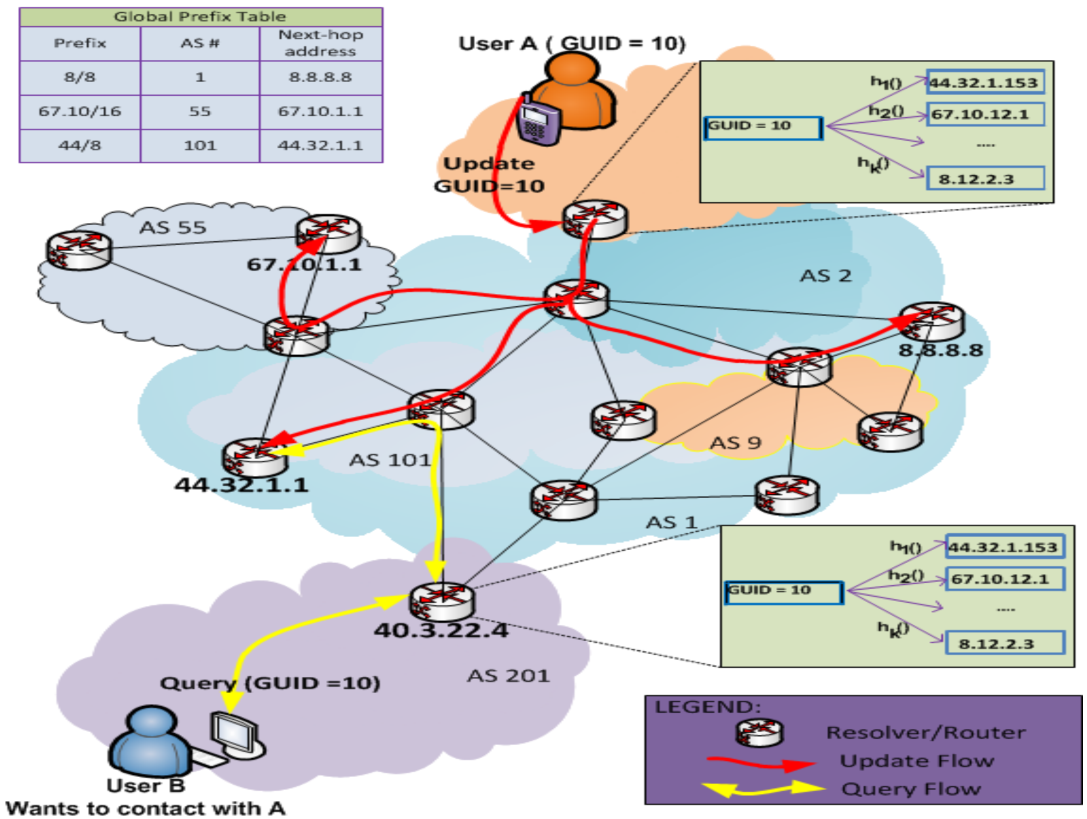
Options = nearest, all, ..

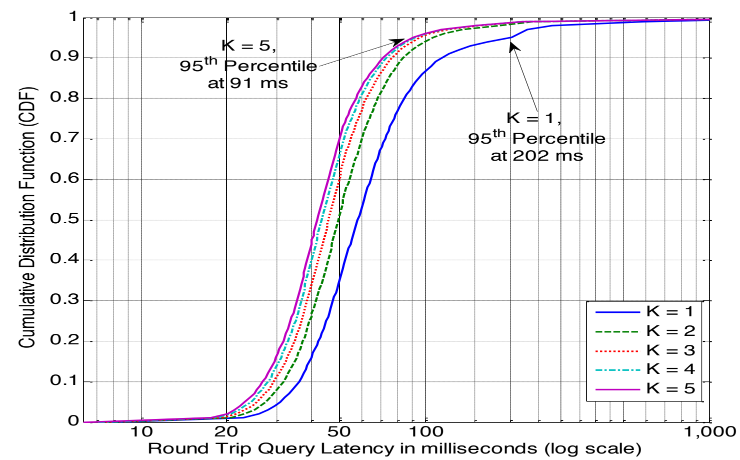


Protocol Design: Realizing the GNRS

- Fast GNRS implementation based on DHT between routers
  - GNRS entries (GUID <-> NA) stored at Router Addr = hash(GUID)
  - Results in distributed in-network directory with fast access (~100 ms)

Global Prefix Table		
Prefix	AS #	Next-hop address
8/8	1	8.8.8.8
67.10/16	55	67.10.1.1
44/8	101	44.32.1.1

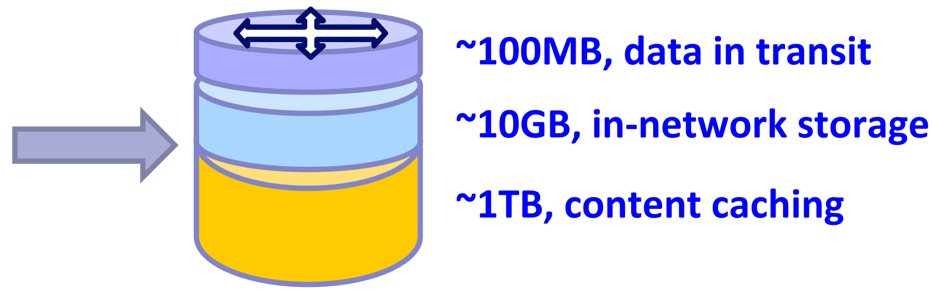




Internet Scale Simulation Results Using DIMES database

Protocol Design: Exploiting In-Network Storage for Routing

Take advantage of cheap storage in the network (*storage-aware routing*)



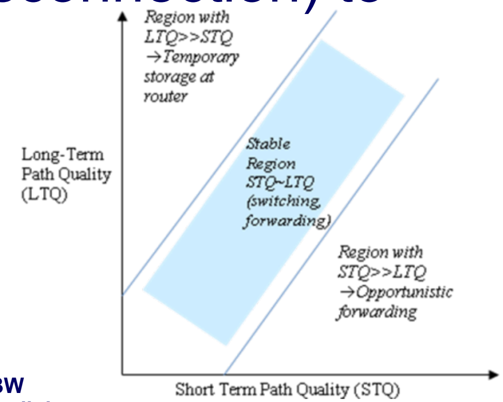
- Expands routing options
  - *Store* and/or *replicate* as feasible routing options
  - Enables "late binding" routing algorithms
- Hop-by-hop transport
  - Large *blocks* reliably transferred at link layer
  - Entire block can be stored or cached at each router

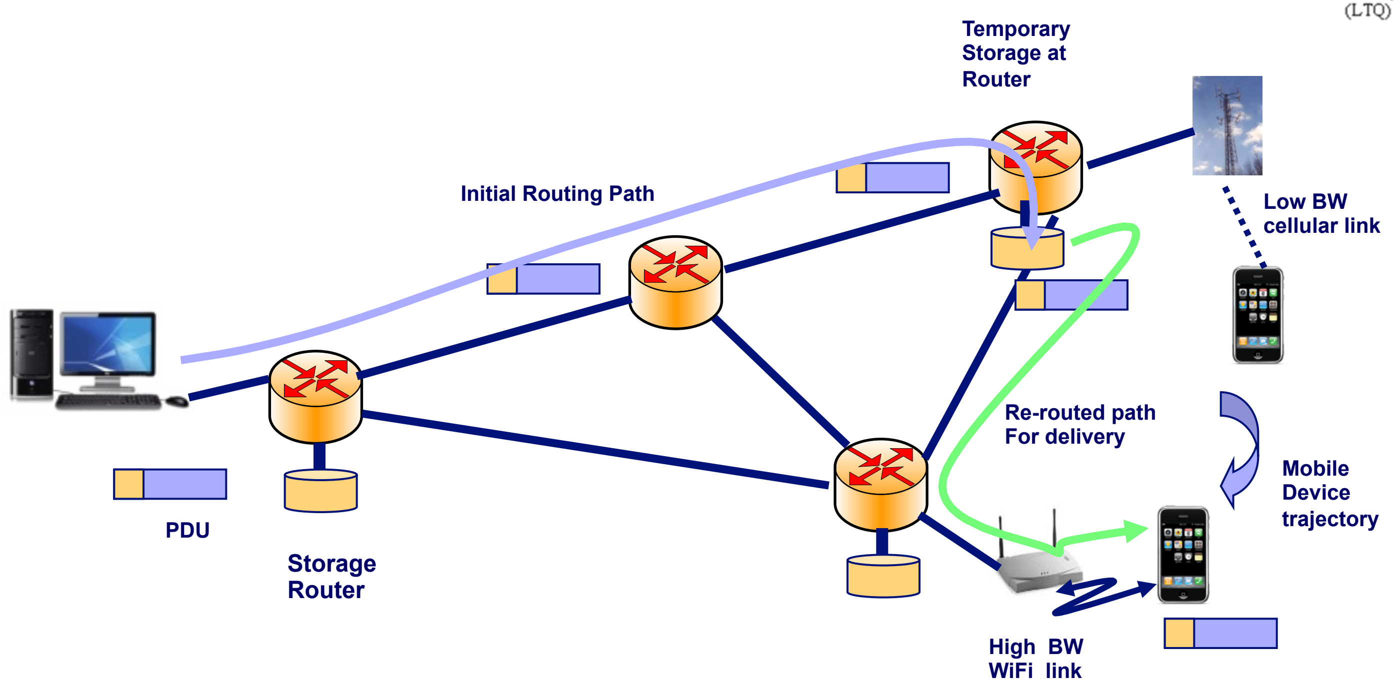
Generalized Storage-Aware Routing

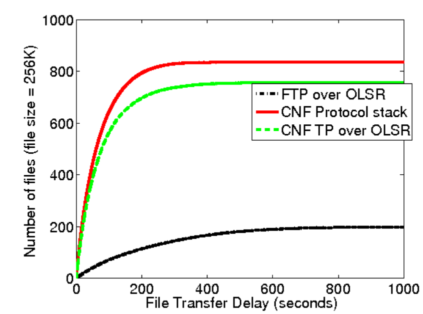
- **Actively monitor link qualities of network**
- **Router store or forward decision based on:**
  1. Short and long term link qualities
  2. Available storage along path
  3. Connectivity to destination

Protocol Design: Storage-Aware Routing (GSTAR)

- Storage aware (CNF, generalized DTN) routing exploits in-network storage to deal with varying link quality and disconnection
- Routing algorithm adapts seamlessly adapts from switching (good path) to store-and-forward (poor link BW/short disconnection) to DTN (longer disconnections)
- Storage has benefits for wired networks as well..



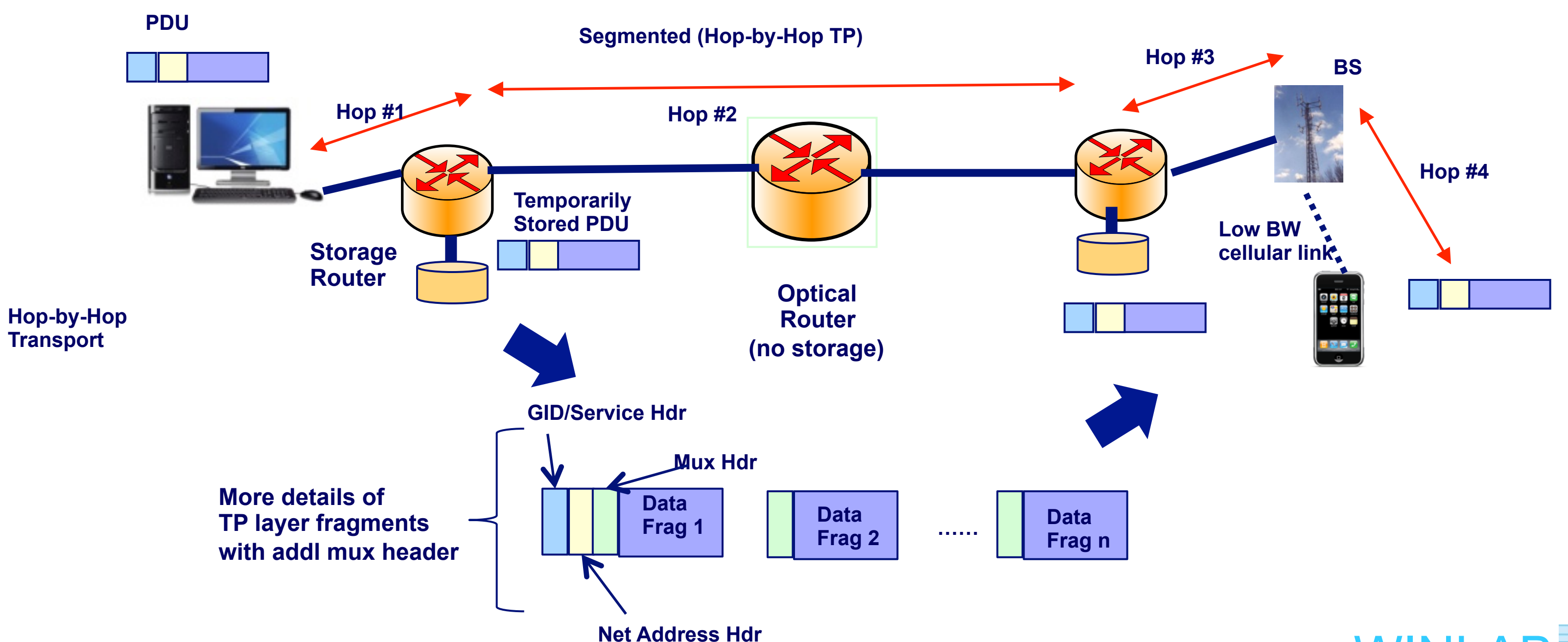




Sample CNF routing result

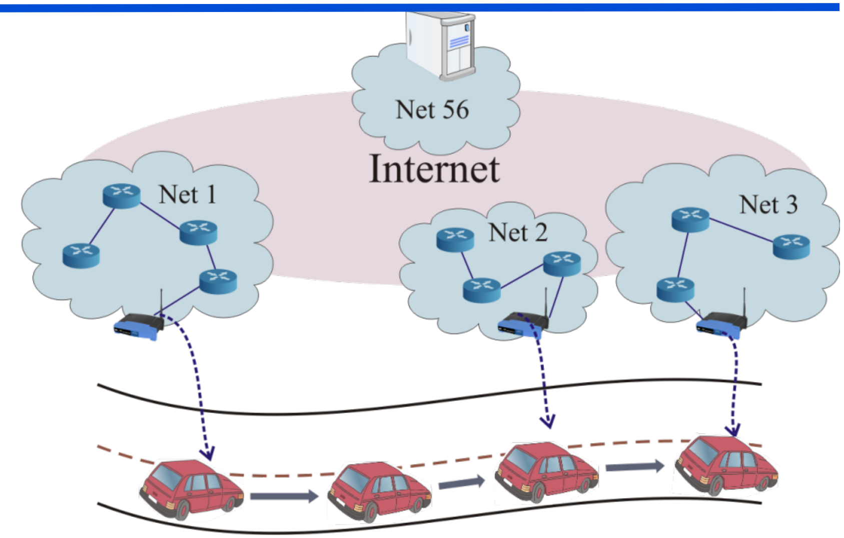
Protocol Design: Segmented Transport

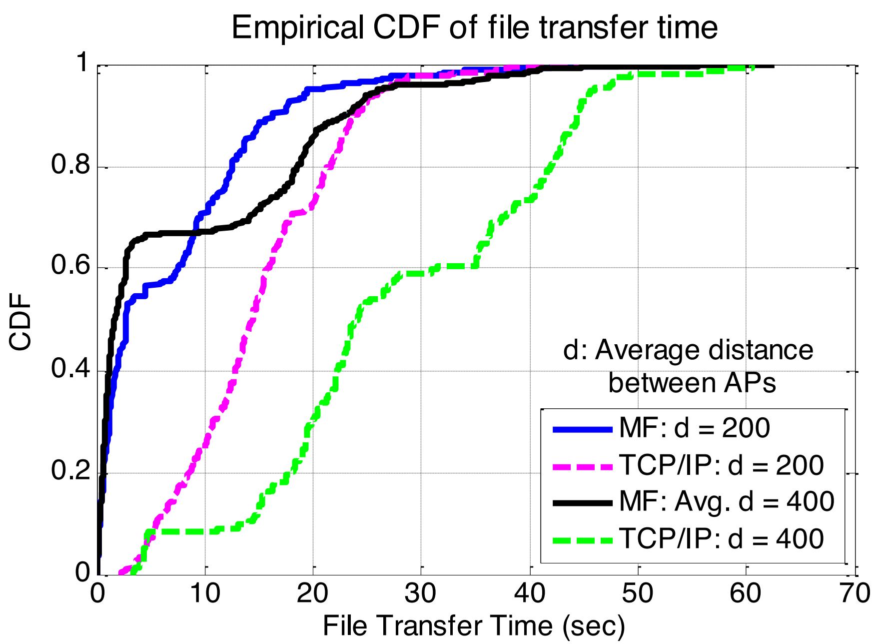
- Segment-by-segment transport between routers with storage, in contrast to end-to-end TCP used today
- Unit of transport (PDU) is a content file or max size fragment
- Hop TP provides improved throughput for time-varying wireless links, and also helps deal with disconnections
- Also supports content caching, location services, etc.

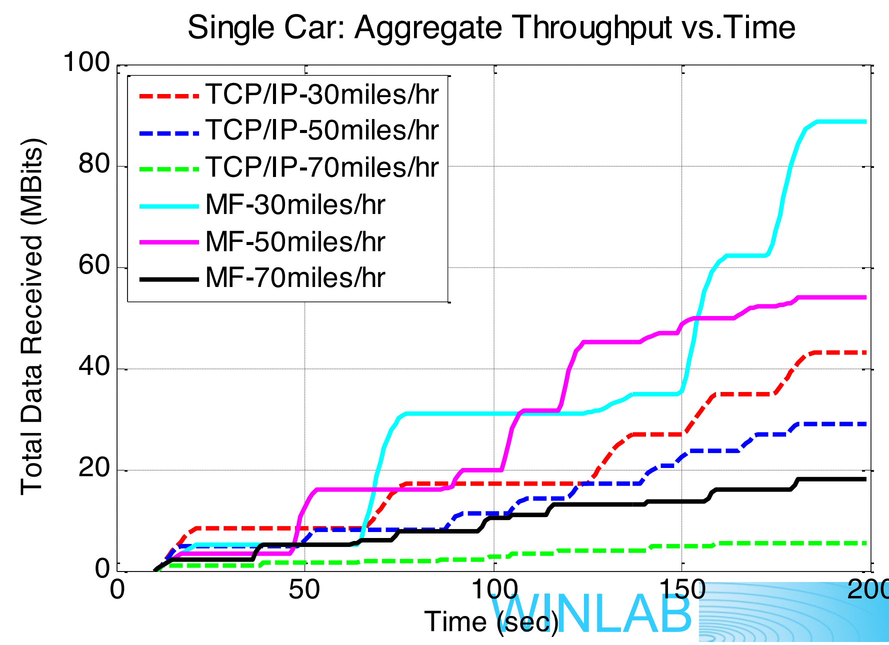


Protocol Design: GNRS + Storage Routing Performance Evaluation

- Detailed NS3 Simulations to compare MF with TCP/IP
- Hotspot AP Deployment: Includes gaps and overlaps
- Cars move according to realistic traces & request browsing type traffic (req. size: 10KB to 5MB)



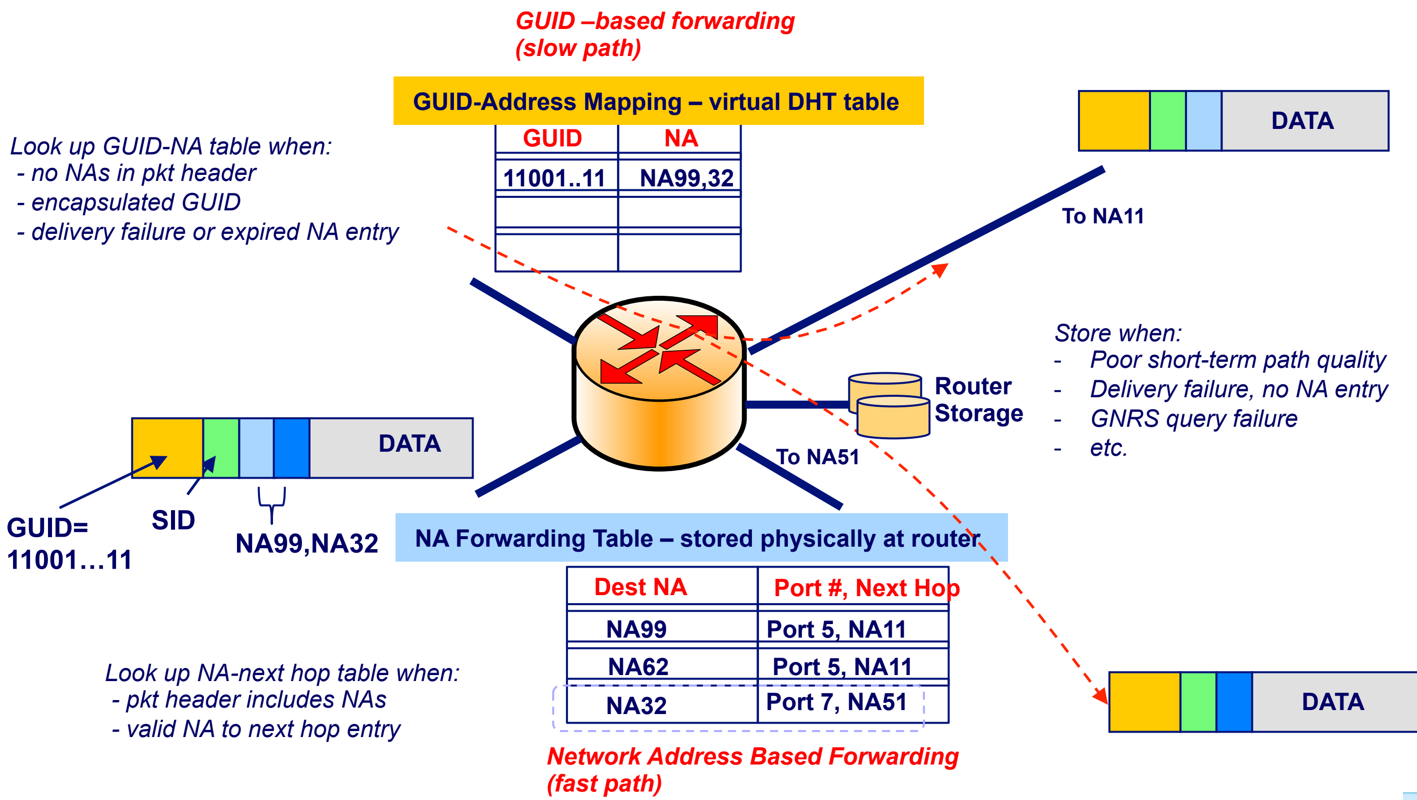




WINLAB

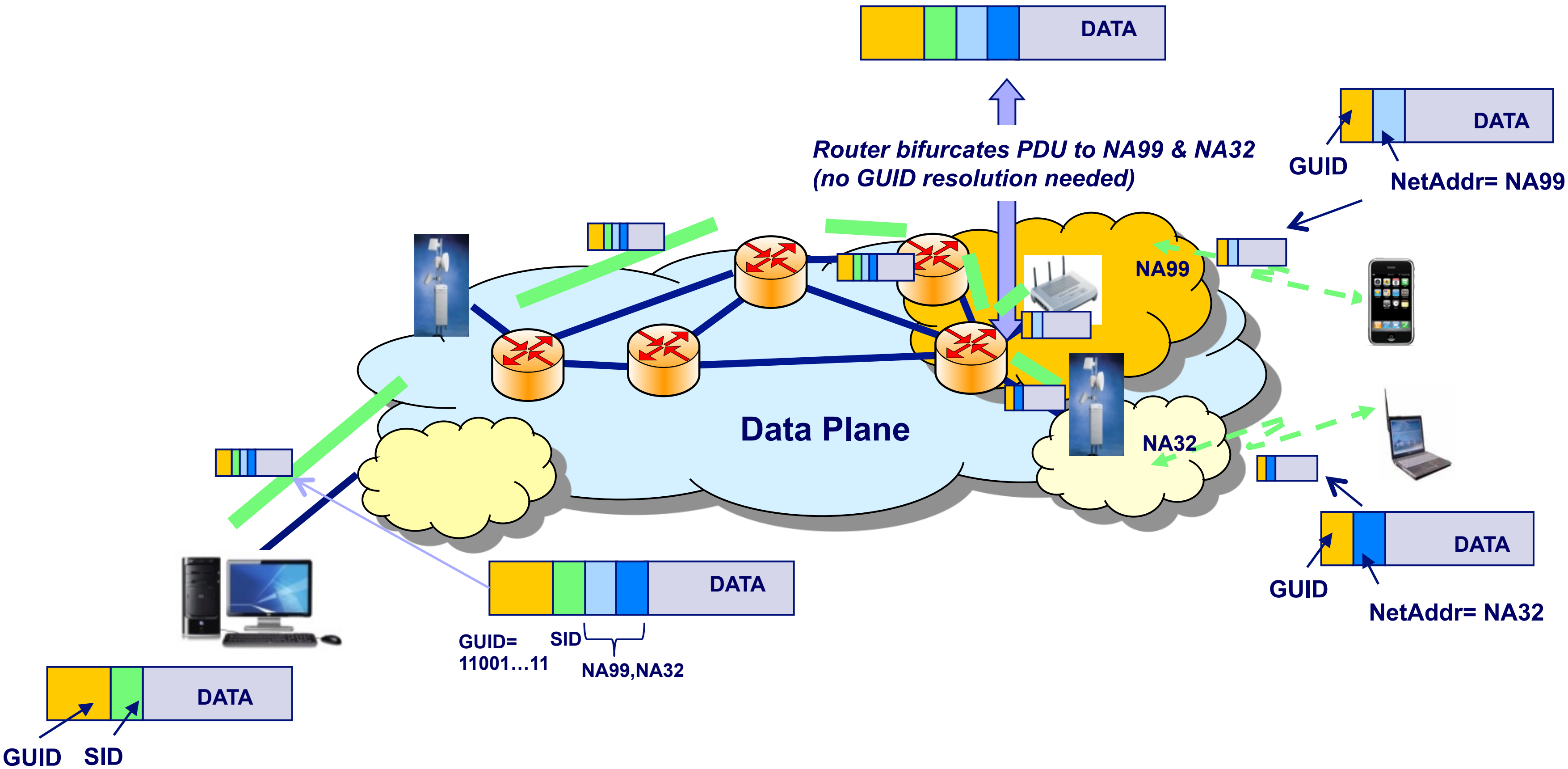
Protocol Design: Hybrid GUID/NA Storage Router in *MobilityFirst*

- **Hybrid name-address based routing in MobilityFirst requires a new router design with in-network storage and two lookup tables:**
  - “Virtual DHT” table for GUID-to-NA lookup as needed
  - Conventional NA-to-port # forwarding table for “fast path”
  - Also, enhanced routing algorithm for store/forward decisions



Protocol Example: Per-Packet Multicast

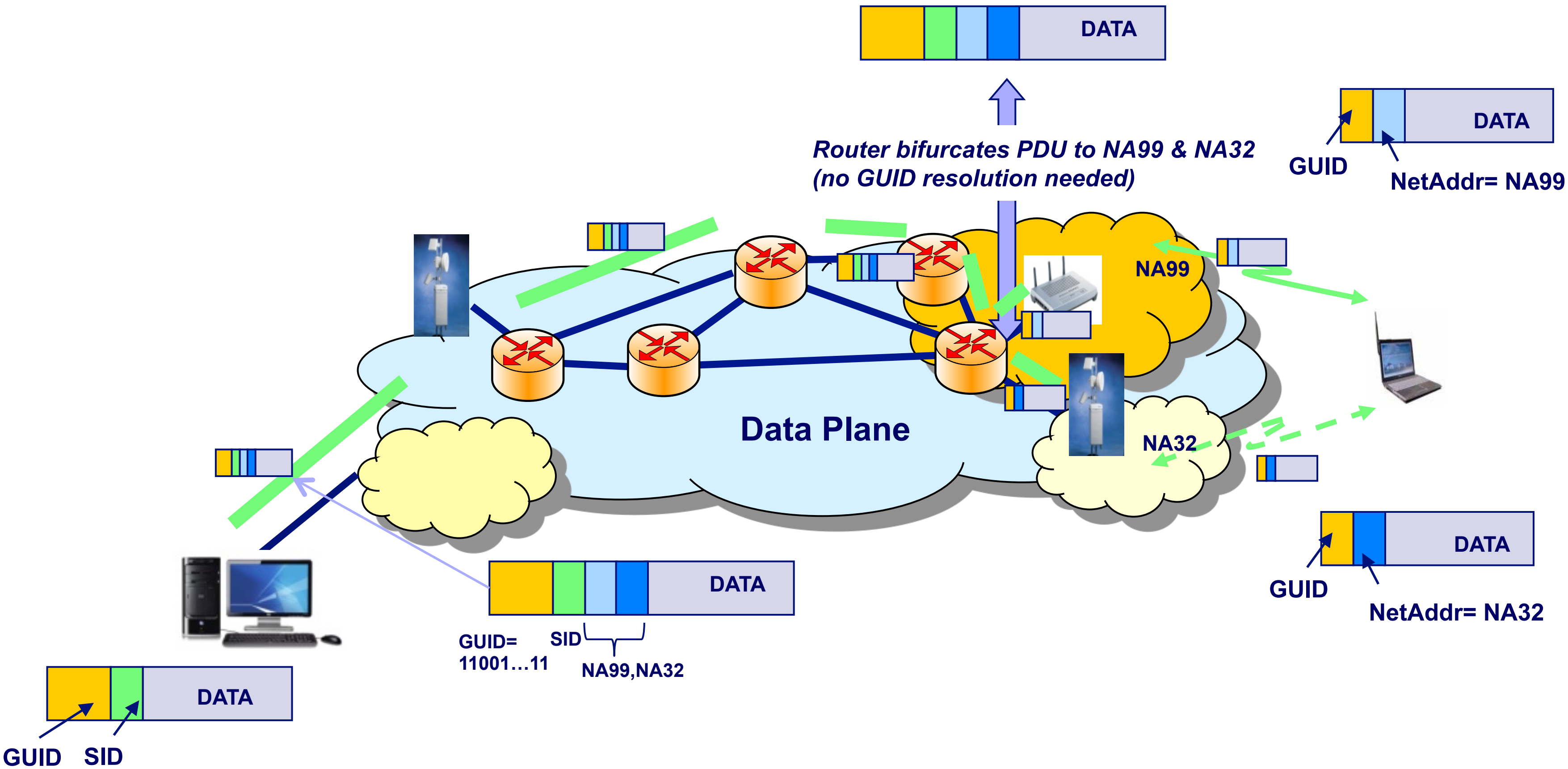
Multicast service example



Send data file to "John Smith22's devices", SID= 21 (mcast)

Protocol Example: Dual Homing Service

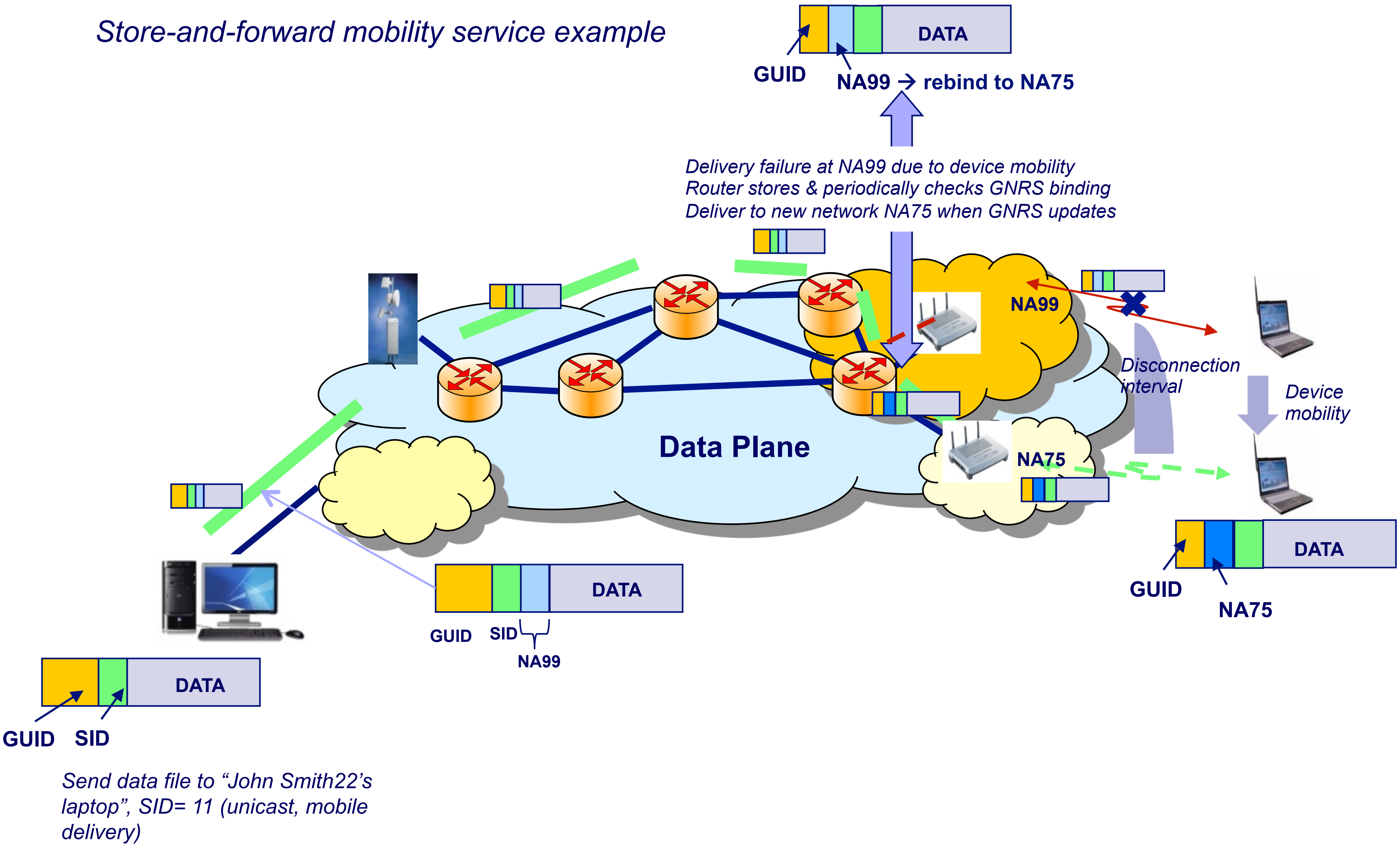
Multihoming service example



Send data file to "John Smith22's laptop", SID= 129 (multihoming – all interfaces)

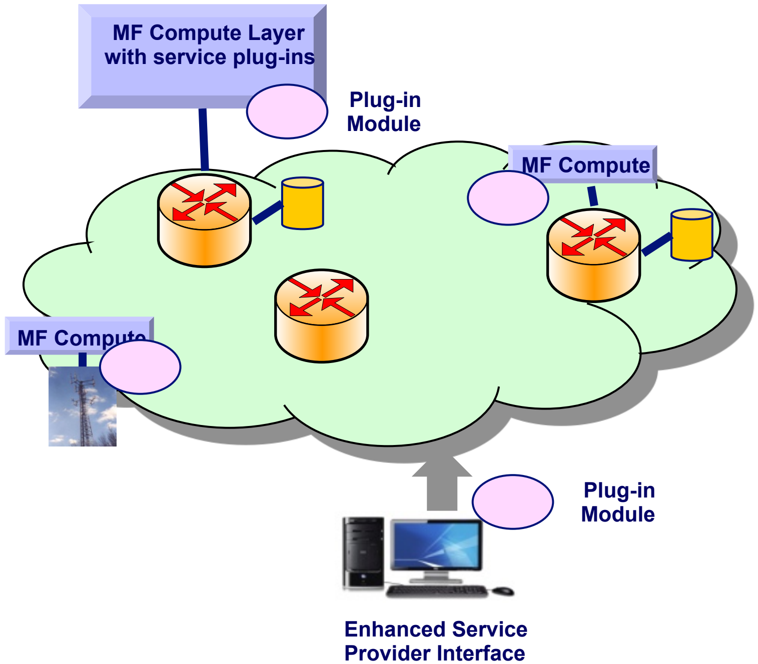
Protocol Example: Handling Disconnection

Store-and-forward mobility service example



Protocol Design: Computing Layer

- Programmable computing layer provides service flexibility and evolution/growth path
  - Routers include a virtual computing layer to support new network services
  - Packets carry service tags and are directed to optional services where applicable
  - Programming API for service creation provided as integral part of architecture
  - Computing load can be reasonable with per-file (PDU) operations (vs. per packet)

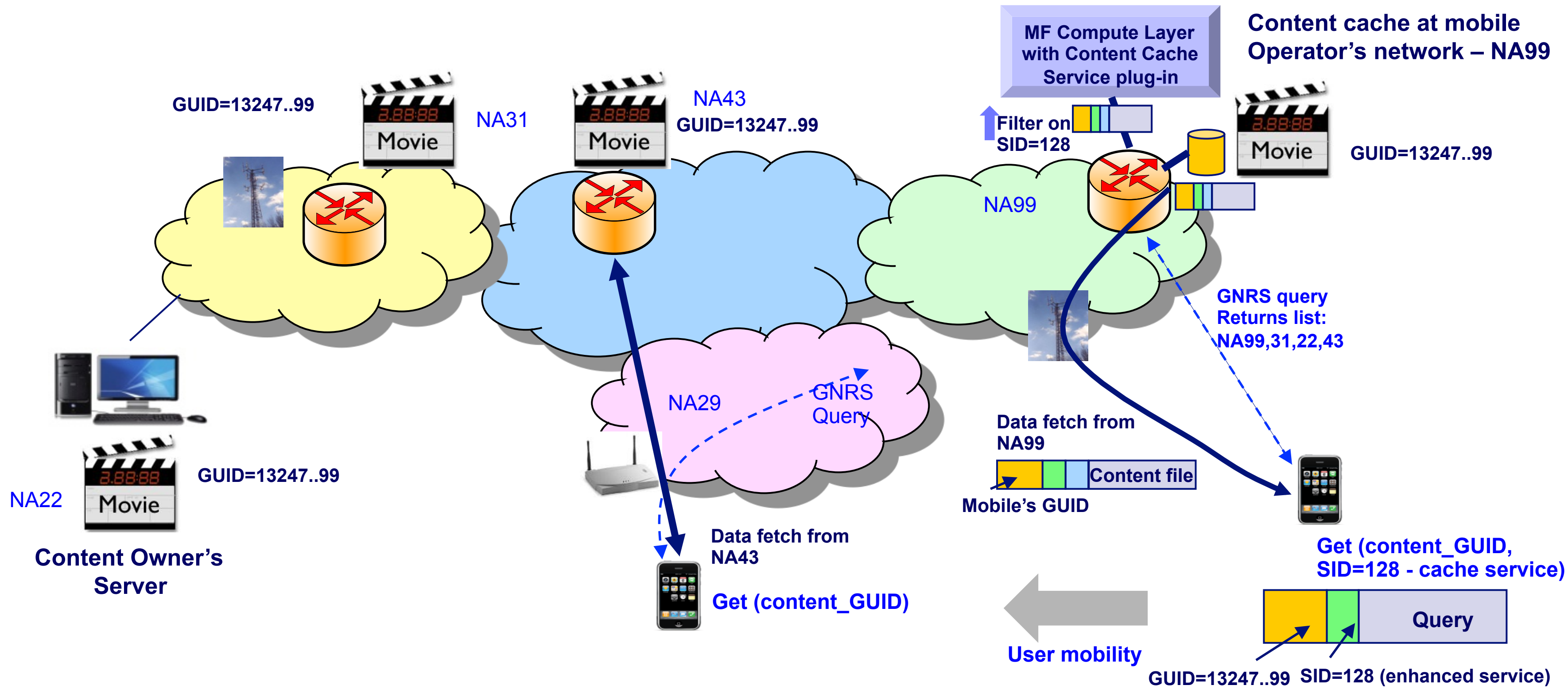


Protocol Design: Content Delivery in MobilityFirst

- Content delivery handled efficiently by proposed MF architecture
  - "Content objects" identified by unique GUID
  - Multiple instances of content file identified by GNRS via GUID to NA mapping
  - Routing protocol used for "reverse anycast" to nearest content object
- Approach differs from NDN/CCN, where content attributes are carried in packet headers
- MF uses content GUID naming service & GNRS to keep things general and avoid interpreting content semantics inside network
- Optional **computing layer** to support enhanced services such as content caching

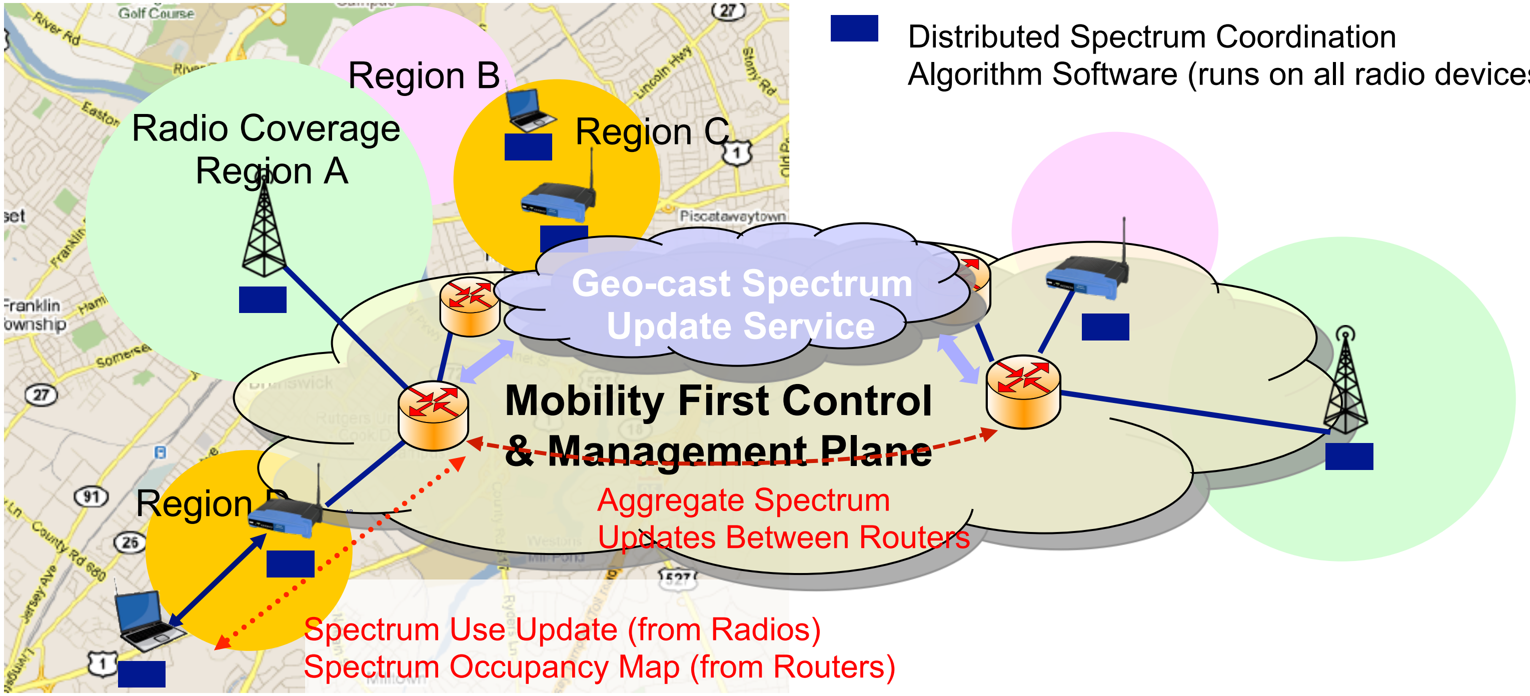
Protocol Example: Enhanced CDN Service

Enhanced service example – content delivery with in-network storage



Protocol Design: Spectrum Management Service

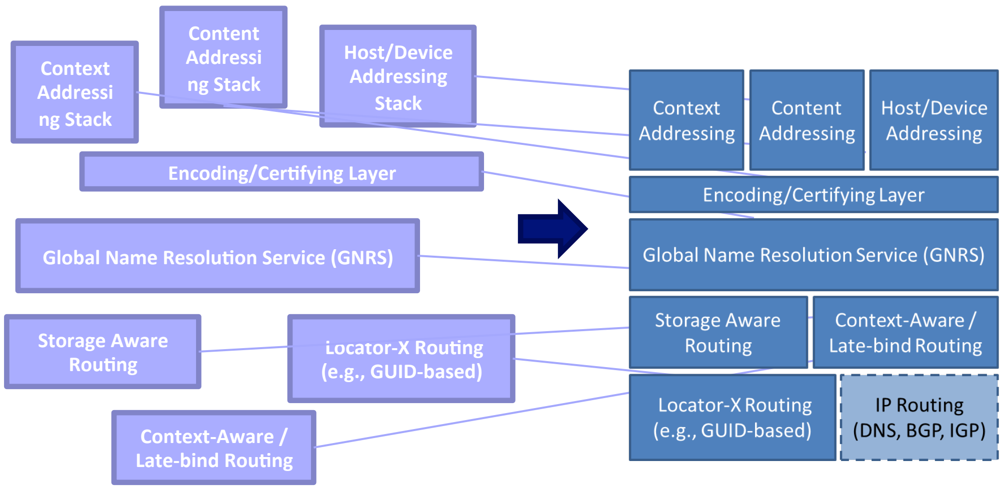
- Dynamic spectrum assignment (DSA) feature in MF management plane
  - Standardized interface for reporting and negotiation of radio resource parameters
  - Geocast routing for distribution of radio maps in region of interest
  - Distributed spectrum coordination algorithms at each network

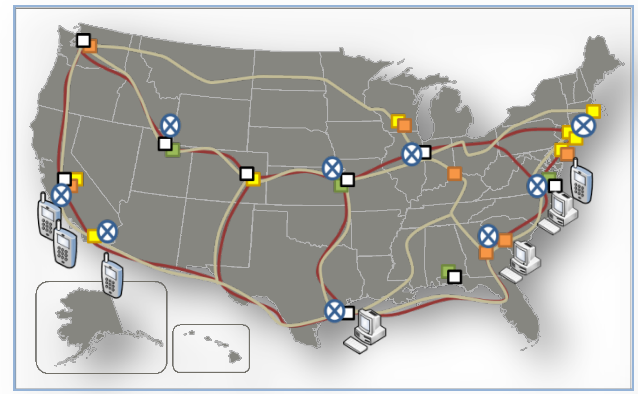


MobilityFirst Protocol Prototyping & Validation

MobilityFirst Prototyping: Phased Strategy

Phase 1 | Phase 2 | Phase 3





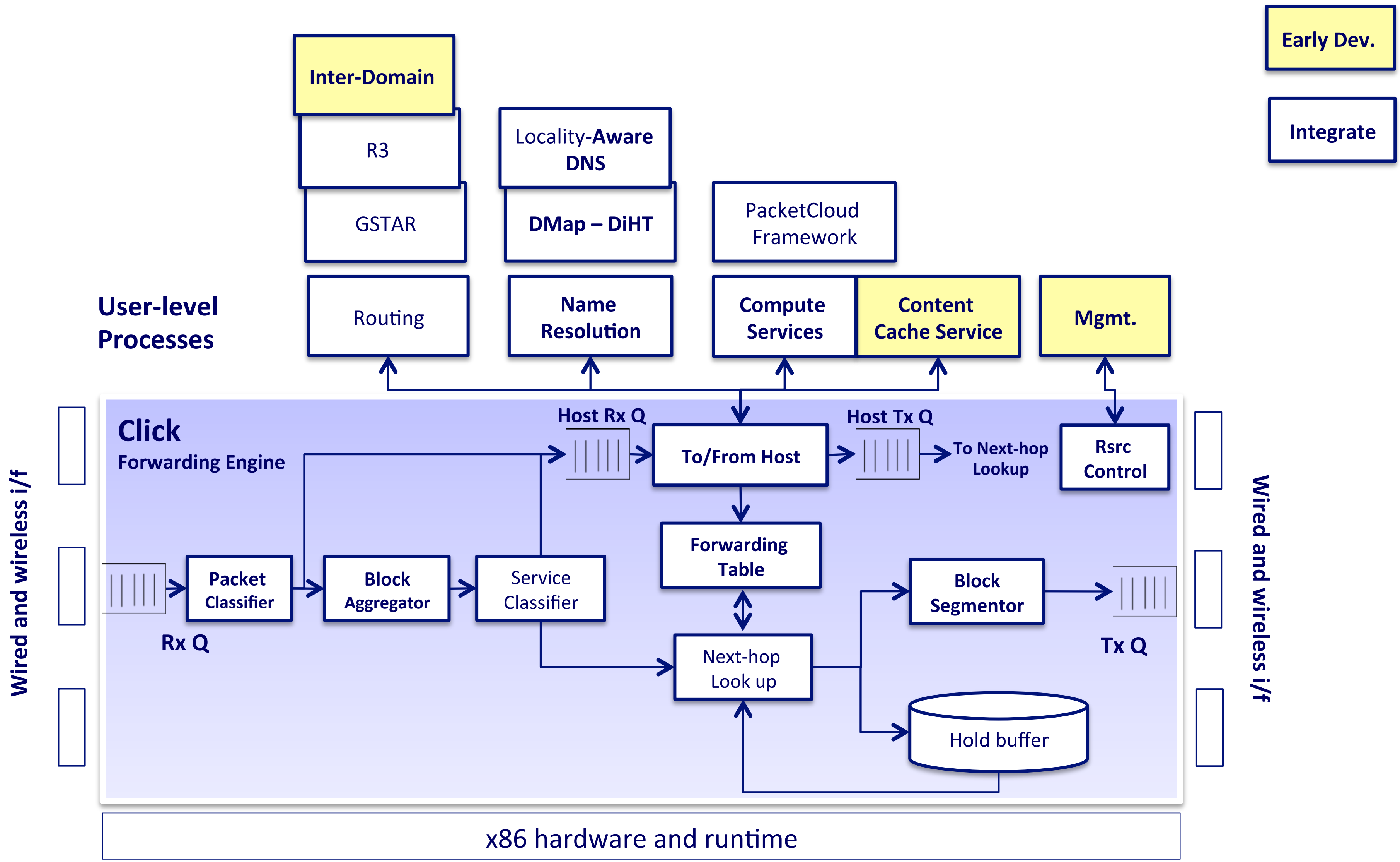
Prototype

Standalone Modules → Integrated MF Protocol Stack and Services → Deployable s/w pkg., box

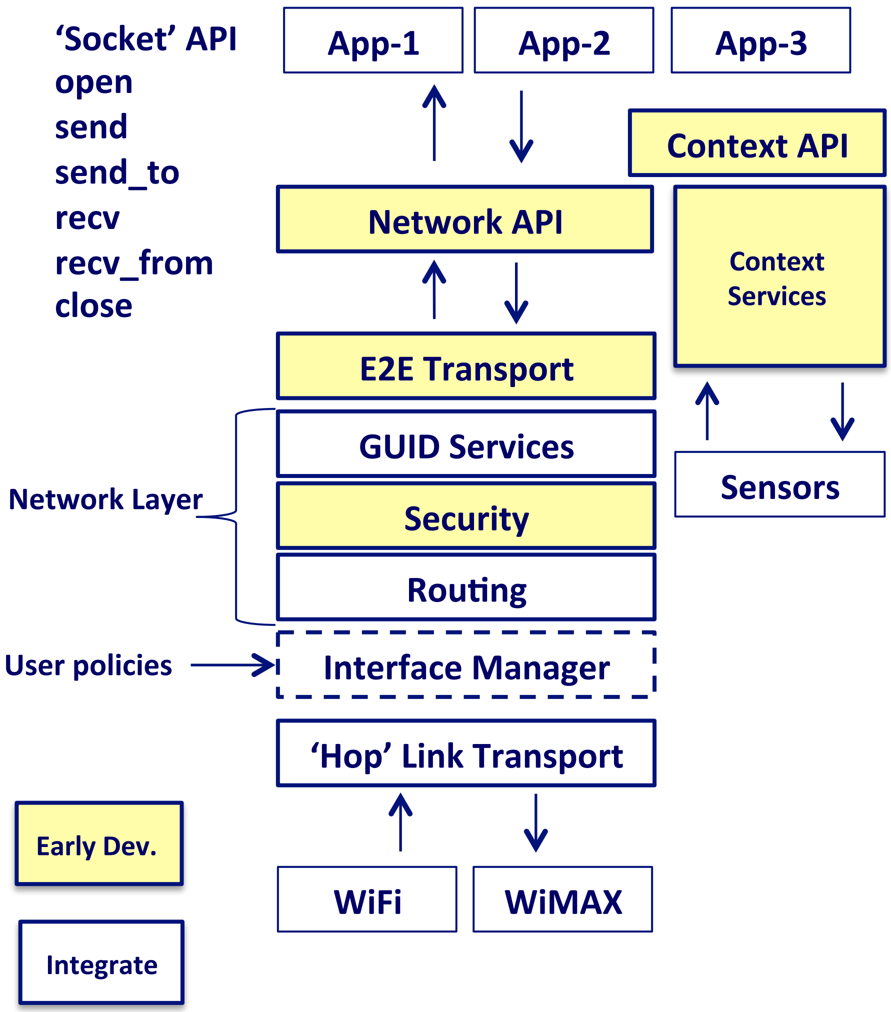
Evaluation

Simulation and Emulation → Smaller Scale Testbed → Distributed Testbed E.g. ‘Live’ on GENI

MobilityFirst Prototyping: Click-based Router Implementation



MobilityFirst Prototyping: Host Protocol Stack

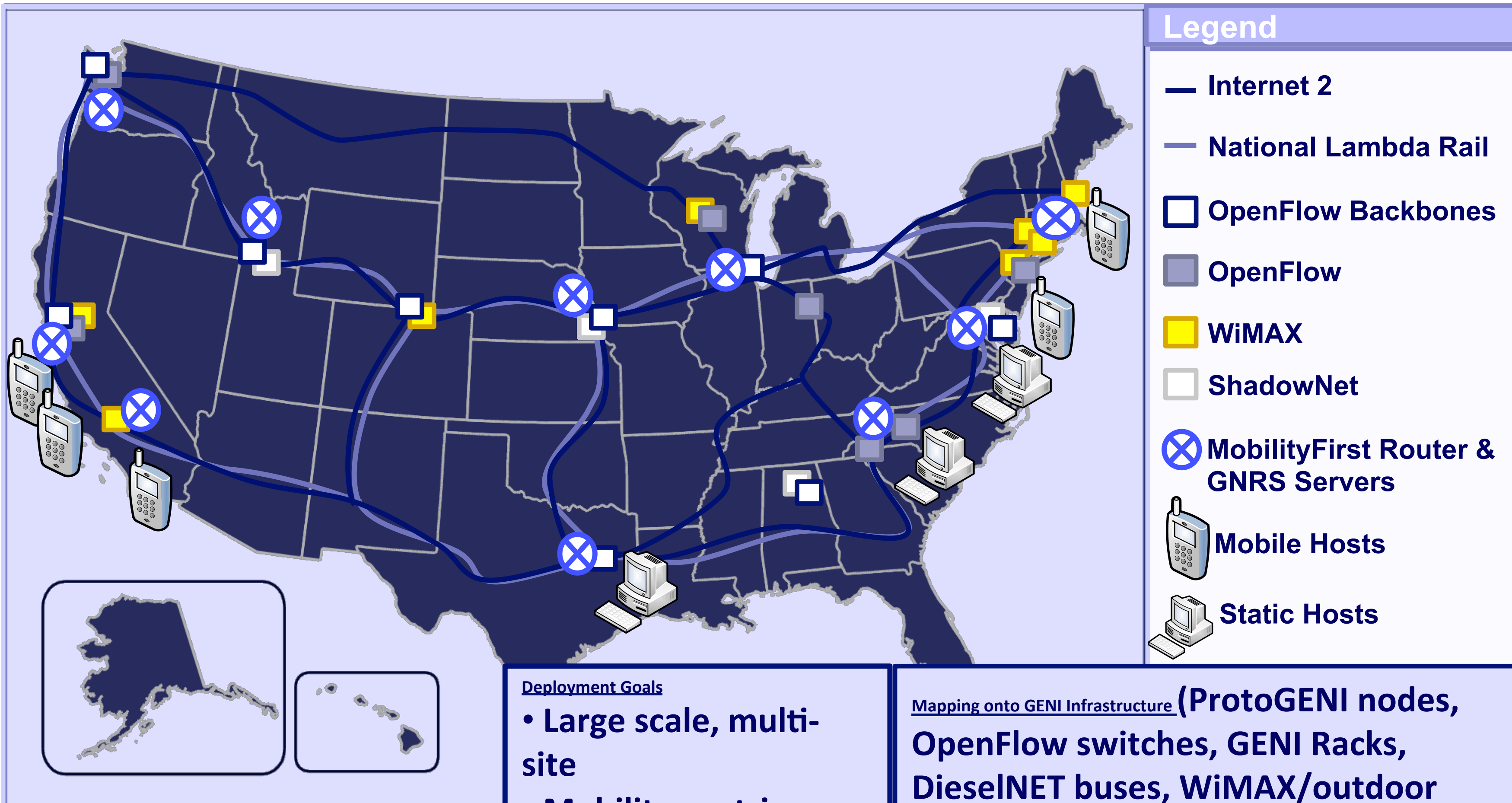


Linux PC/laptop with WiMAX & WiFi

Android device with WiMAX & WiFi

Device: HTC Evo 4G, Android v2.3 (rooted), NDK (C++ dev)

MobilityFirst Prototyping: GENI Deployment

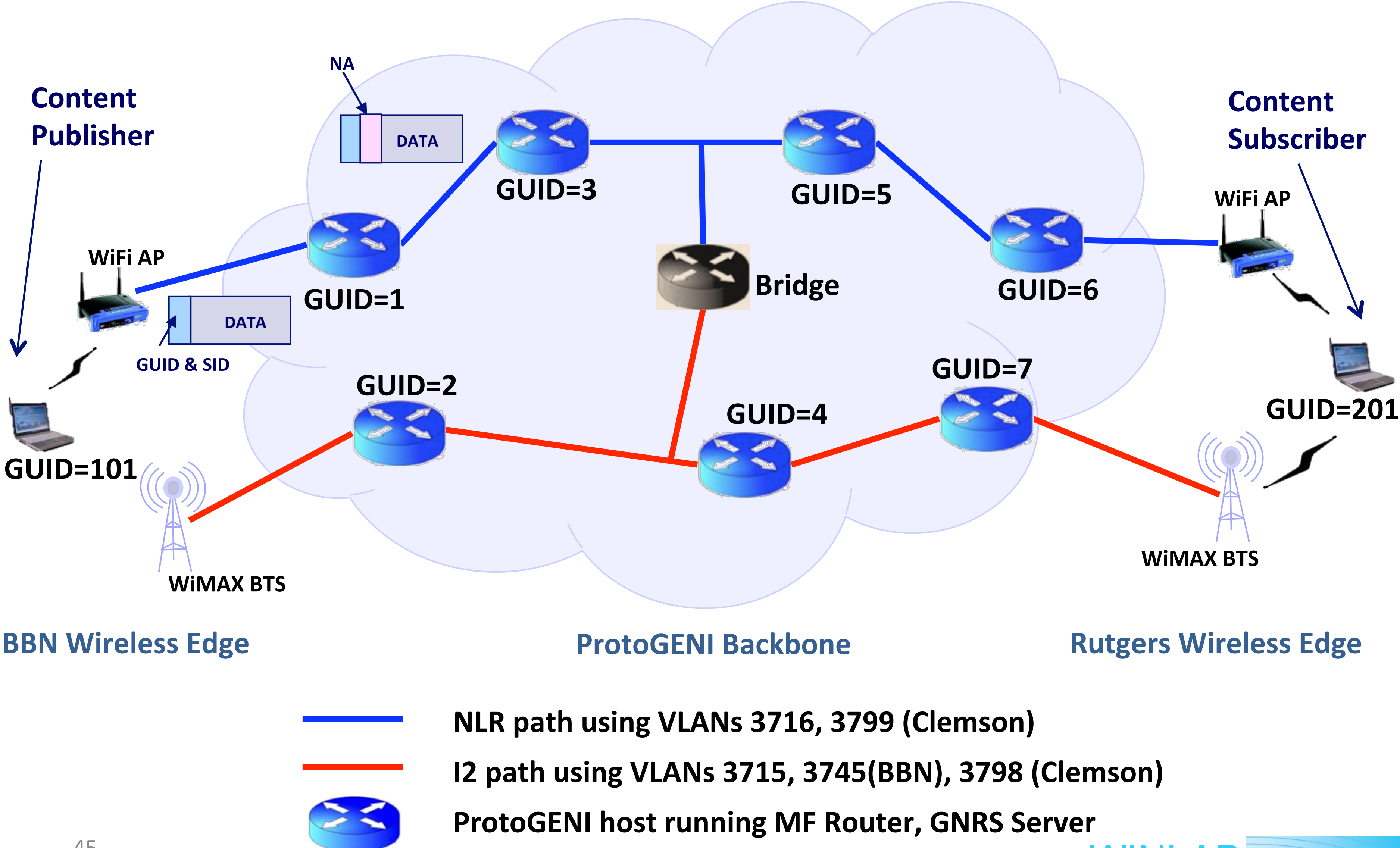


Deployment Goals

- Large scale, multi-site
- Mobility centric
- Realistic, live

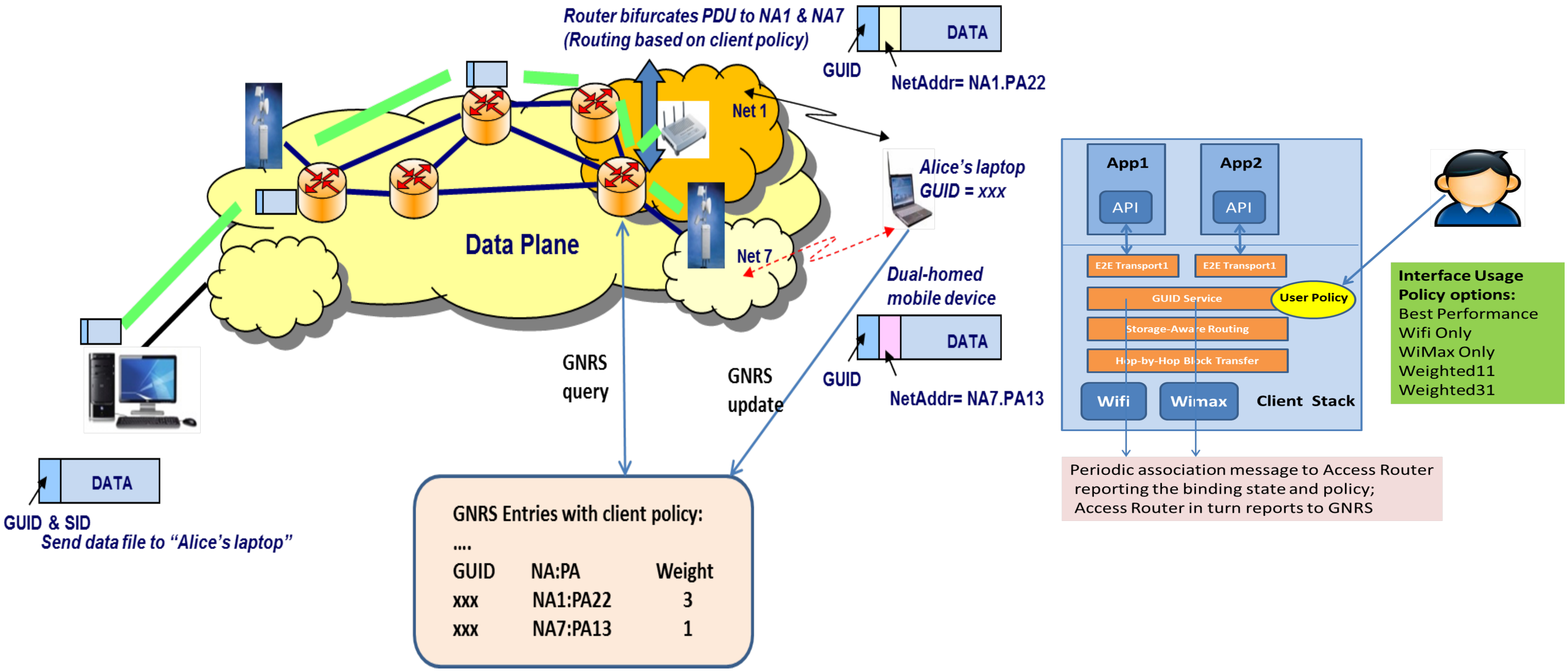
Mapping onto GENI Infrastructure (ProtoGENI nodes, OpenFlow switches, GENI Racks, DieselNET buses, WiMAX/outdoor ORBIT nodes)

MobilityFirst Prototyping: GEC-12 Demo (Content Delivery), ~11/11

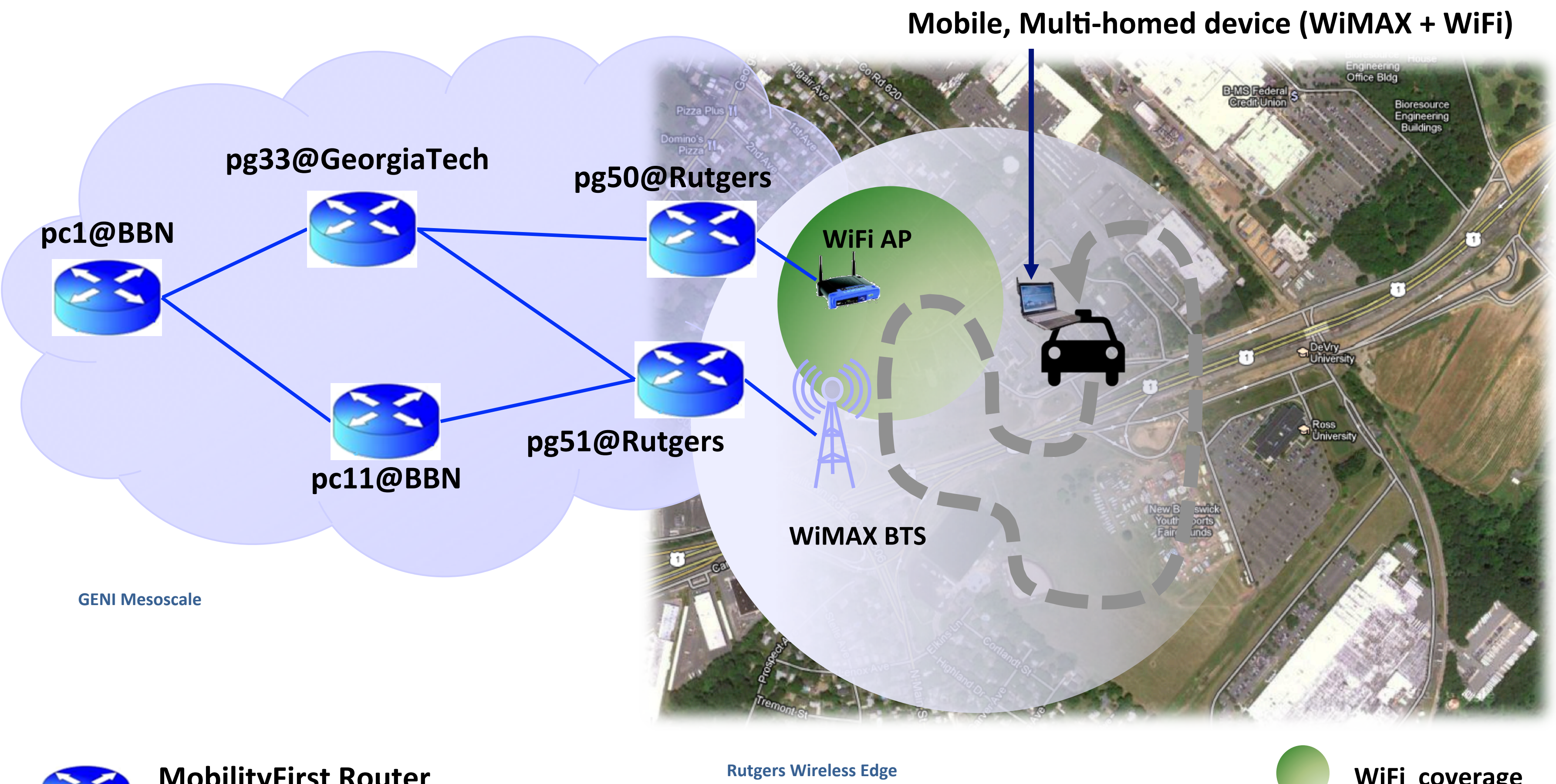


MobilityFirst Prototyping: Hot Mobile 2012

Delivery Services for Multi-Homed Devices with User preference of delivery interface



MobilityFirst Prototyping: GEC-13 Demo (Mobility, Multi-homing), ~3/12



Resources

- Project website: http://mobilityfirst.winlab.rutgers.edu
- GENI website: www.geni.net
- ORBIT website: www.orbit-lab.org