Engineering Research Center for
Collaborative Adaptive Sensing of the Atmosphere

Distributed Multi-Sensor Data Fusion Over Named Data Networks

H. M. N. Dilum Bandara and Anura P. Jayasumana
Dept. of Electrical & Computer Engineering,
Colorado State University, Fort Collins, CO 80523, USA.

dilumb@uom.lk
http://dilum.bandara.lk


University of Massachusetts Amherst


University of Oklahoma

Colorado State University


University of Puerto Rico Mayaguez

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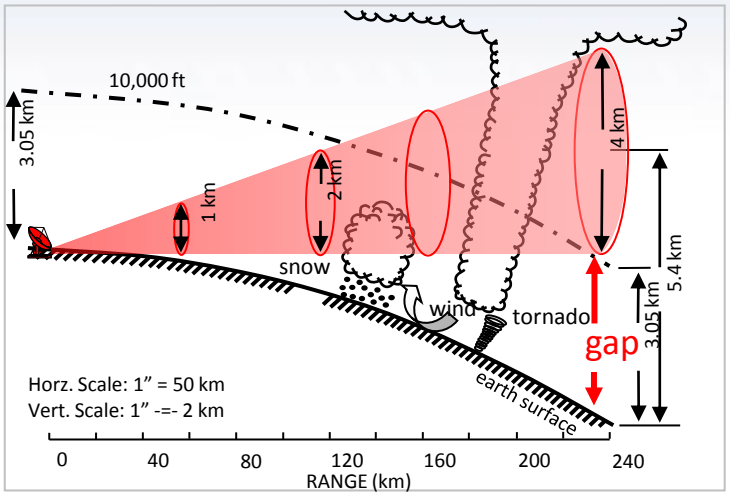
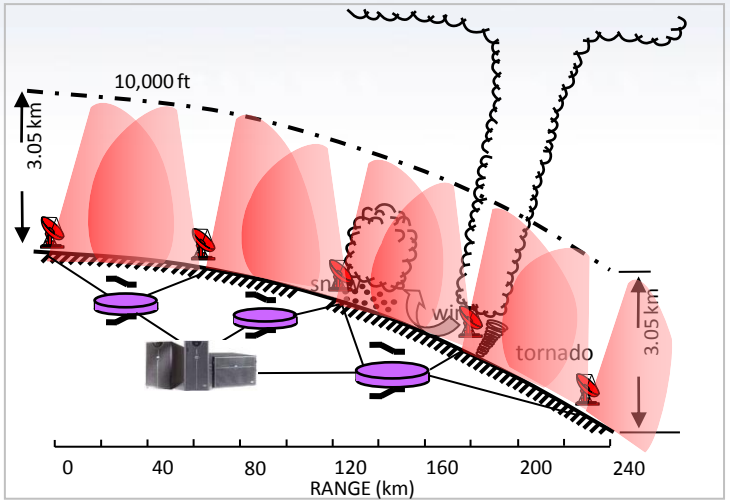
Contributions

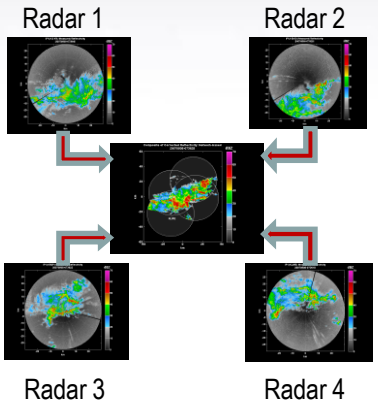
Demonstrated applicability of Named Data Networking (NDN) for Distributed Collaborative Adaptive Sensing (DCAS) systems

- Multi-user, multi-application, & multi-sensor systems

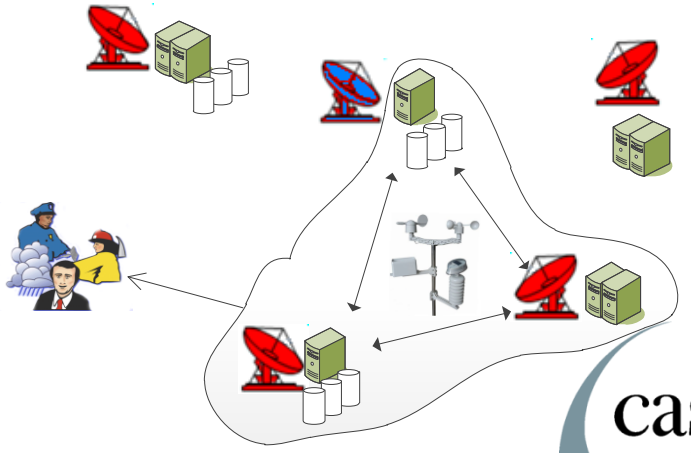
Collaborative Adaptive Sensing of the Atmosphere (CASA)





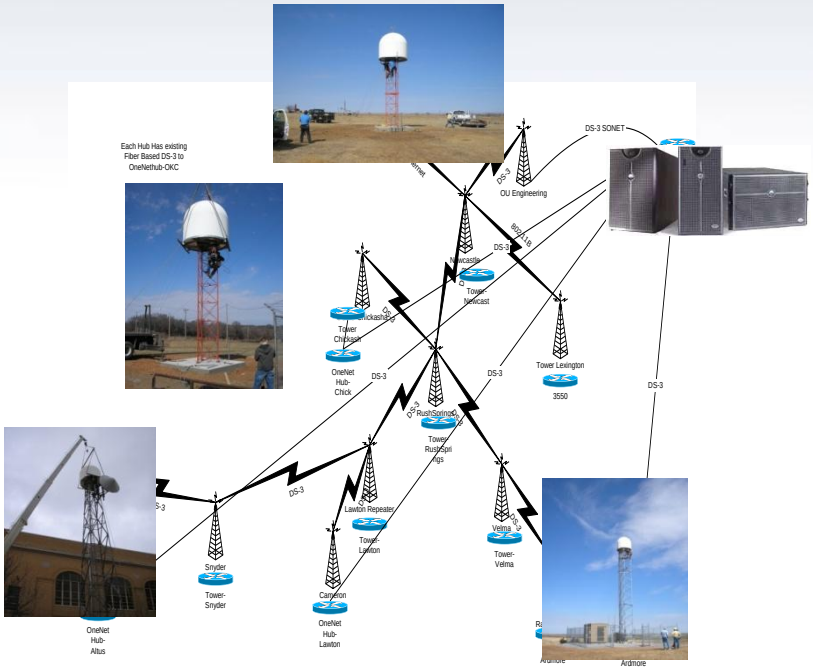


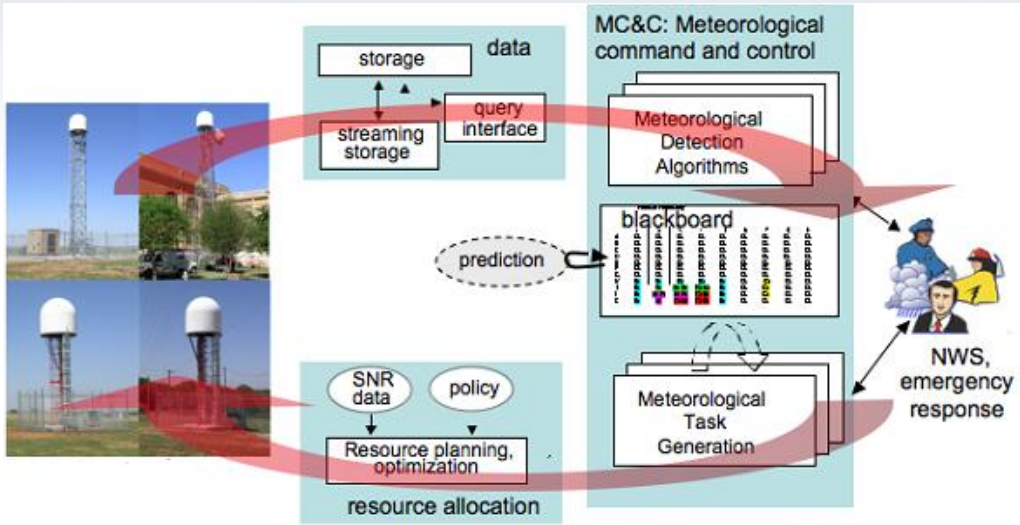
- Collaborating & adapting radars
  - Improved sensing, detection, & forecasting
- Aggregates distributed groups of resources as & when needed
  - 10,000 radars to cover U.S.
  - High data rate – 800 Mbps
  - Heterogeneous, dynamic, & distributed
  - Real-time – 30 sec heart beat



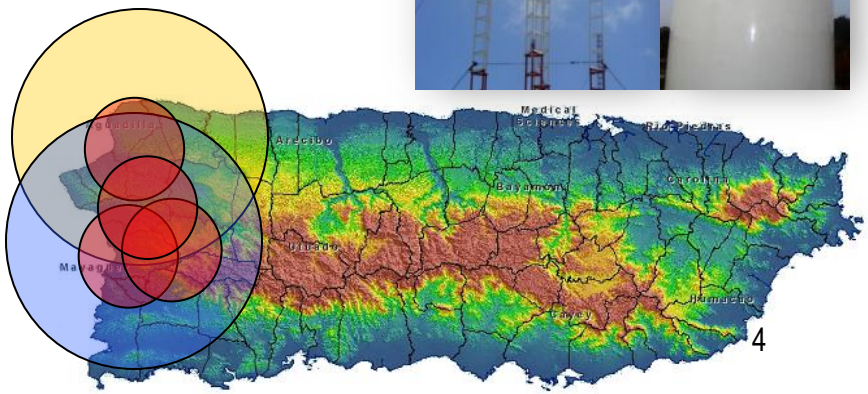
casa

CASA Test Beds





- Oklahoma test bed
  - 7,000 km^2，40 km range, 30 km spacing
  - Connected to the Internet
  - Data pull – 30 sec heart beat
  - Being moved to Dallas-Fort Worth
- Puerto Rico student test bed
  - Solar powered
  - Wireless connections



CASA Applications & End Users

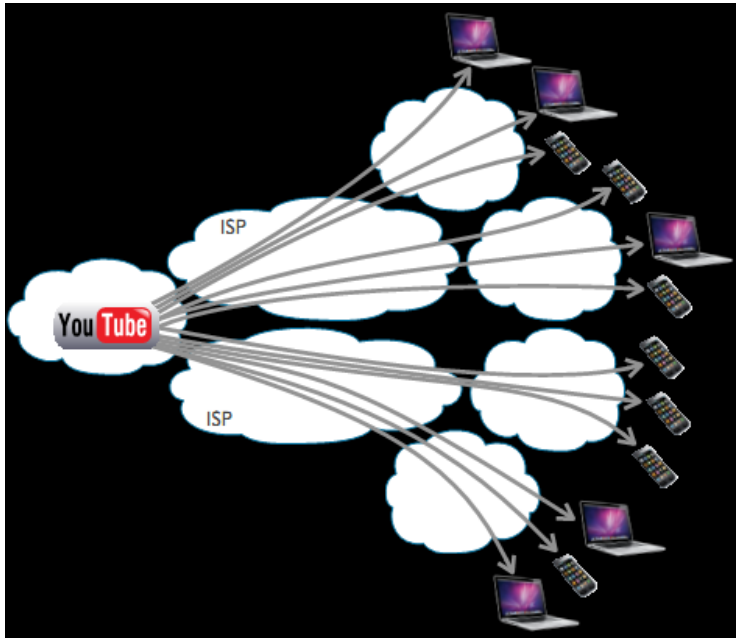
Application	Description	No of Radars	Data Type(s)
Reflectivity	Reflectivity of clouds	1	Reflectivity
Velocity	Wind velocity	2-3	Doppler velocity, reflectivity
Network-Based Reflectivity Retrieval (NBRR)	Reflectivity of clouds detected using multiple radars	3+	Reflectivity
Nowcasting	Short term (10-30 min) high resolution forecasts of active weather events	1-3	Reflectivity
Tornado tracking	Detect & track a tornado as it forms & moves	2+	Doppler velocity, reflectivity

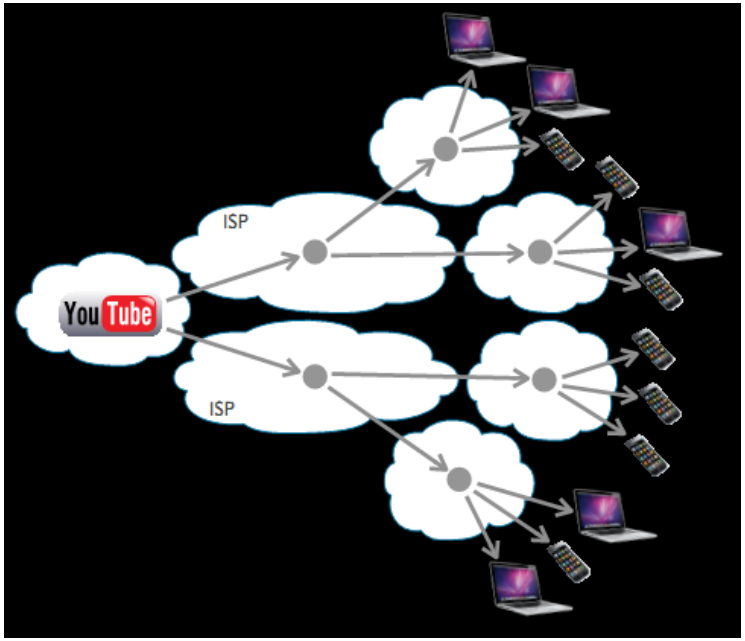
End user	Description	Applications	Rule Trigger	AOI	Sampling Interval
National Weather Service (NWS)	Responsible for issuing warnings	Reflectivity	Periodic	Counties under jurisdiction	1 min
		Velocity			
		NBRR, nowcasting, QPE	High reflectivity	Area of active weather	
		Tornado tracking	Rotating wind, ground spotters		
Emergency Managers (EMs)	Siren blowing, helping first responders, act as spotters	Reflectivity	Periodic	Counties under jurisdiction	1 min
		Velocity			
		NBRR, nowcasting, QPE	High reflectivity	Area of active weather	2 min
		Tornado tracking	Rotating wind, ground spotters		1 min
Researchers	To understand physical properties of weather events, test new algorithms	Reflectivity	Periodic	Area of active weather	1 min
		Velocity	High wind		30 sec
		NBRR, nowcasting, QPE	High reflectivity		1 min
		Tornado tracking	Rotating wind		30 sec

- Same data accessed by multiple applications & end users

Named Data Networking (NDN)

- Internet was designed to share resources
- Today, Internet users value ability to access contents
  - End/location is irrelevant
  - Traffic aggregation, location dependence, & security





- V. Jacobson et al., "Networking named content," CoNEXT '09, Dec. 2009.

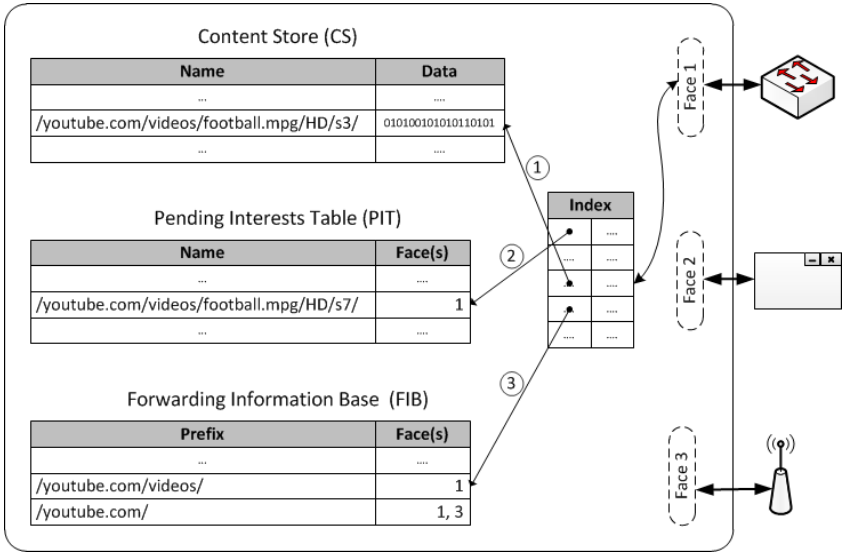
Named Data Networking (Cont.)

- Named Data Networking (NDN/CCN)
  - Access & route contents based on application-layer names
  - In-network caching, duplicate message suppression, & better security
  - On demand data generation
  - Incremental deployments

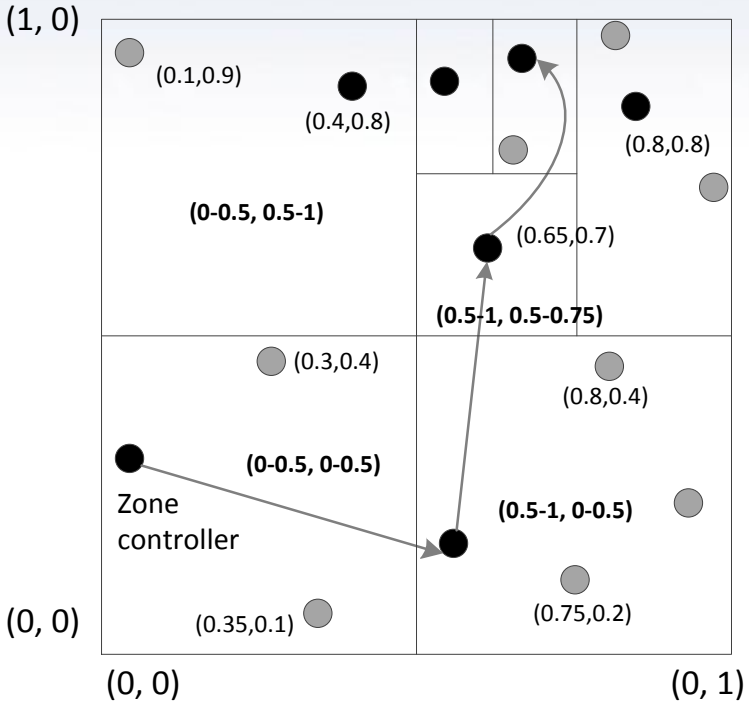
Interests packets – Indicate name of content

- /youtube.com/sports/NFL_finals.mpg/
- /youtube.com/sports/NFL_finals.mpg/HD/S3/
- /machine_room/sensor123/temp/sense/5min/

Data packet – Response to an interest



Content Addressable Network (CAN)



- d-dimensional torus (d-torus)
- $d \geq 2$
- Greedy routing, immune to voids (no local minimas)

- S. Ratnasamy et al., "A scalable content-addressable network," ACM SIGCOMM '01, Aug. 2001.

Distributed Collaborative Adaptive Sensing (DCAS) Systems

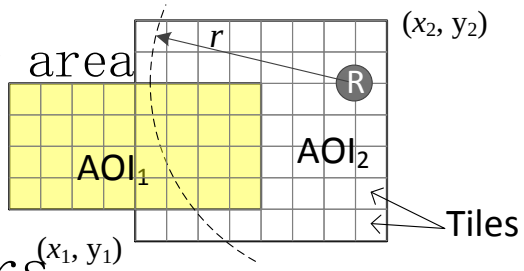
- E.g., CASA, distributed radio telescopes
  - Heterogeneous, redundant, & distributed sensors
  - Multi-user, multi-application, & multi-sensor systems
- Data pull
  - End-user information needs determine how & what groups of system resources are used to generate & process data
- Sensor specific data names
  - Typically bind to sensor
  - "*Reflectivity data from radar X*"
- End users are concerned on an event(s) occurring within an Area Of Interest (AOI)
  - *"Reflectivity over Moratuwa"* or *"Wind in west Moratuwa"*
- Reduce ability to utilize spatial & temporal locality in user interests & redundant sensors

Why NDN for CASA?

Geographic location & weather event specific names • Queries & data • Aliases for same data	Content dependent names • 2 packet types – Interests & data • /Moratuwa/Reflectivity/10:32/ • Multiple names
Decouple data, security, & access from sensor • Use any available sensor	Decouple identity, security, & access from end point
High temporal & spatial locality	Exploit temporal & spatial locality
Pull based • End-user information needs determine what & how resources are used	Receiver driven communication • On demand data generation
Overlay routing	Multiple routing schemes
Load balancing, resilience, & security • Multi-path routing & mobility	Better reliability & security • Multi-path routing & mobility

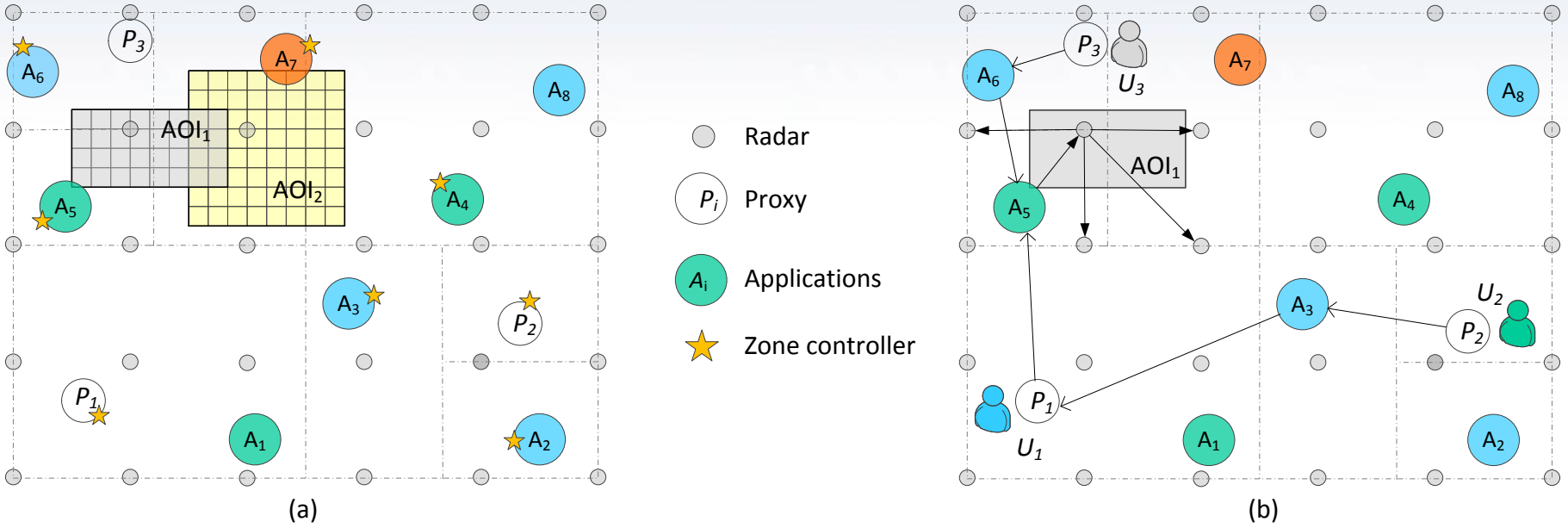
NDN for DCAS – Naming Data

- End users specify an AOI, application, & time
  - /AOI/application/time/
  - Interest packet is looking for an application near AOI
    - Process data close to source → Save bandwidth
  - AOI is typically expressed as a rectangular area
    - /x_1/y_1/x_2/y_2/application/time
    - Larger AOIs are broken into smaller ones



- Application needs to subscribe to radars
  - CASA radars negotiate among themselves on how to provide data
  - /x_1/y_1/x_2/y_2/radar/time/subscription/n/dataType
- Application pull data from selected radars
  - /x_R/y_R/x_R/y_R/radar/time/x_1/y_1/x_2/y_2/bitmap/dataType

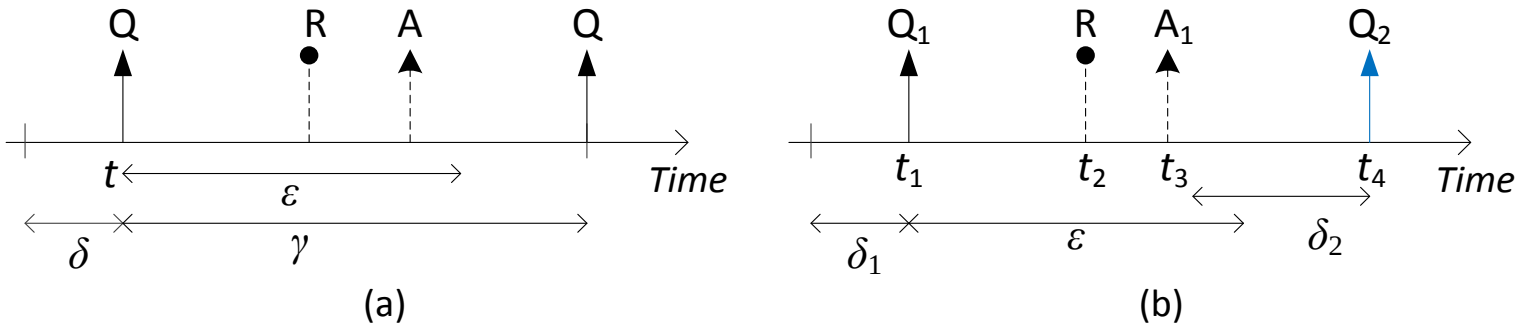
NDN for DCAS – Overlay Construction & Query Resolution



- Overlay routing – Content Addressable Network (CAN)
  - Maps to 2D space while preserving locality
  - No local minimas as in other greedy routing solutions
- End users connect to overlay using a set of proxies

Subscription & Caching

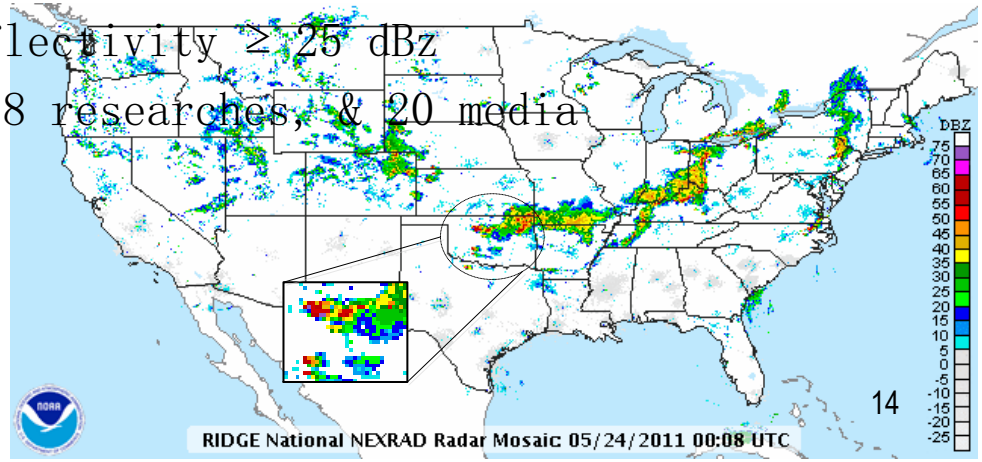
- Subscription scheme for periodic queries
  - Adjust interest issue time at a proxy



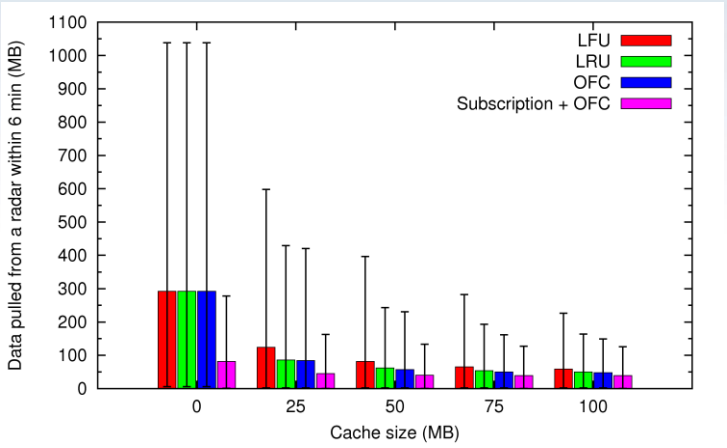
- Oldest First Caching (OFC)
  - Users interested in recent data
  - Less important with time
  - When cache is full remove the oldest data packet

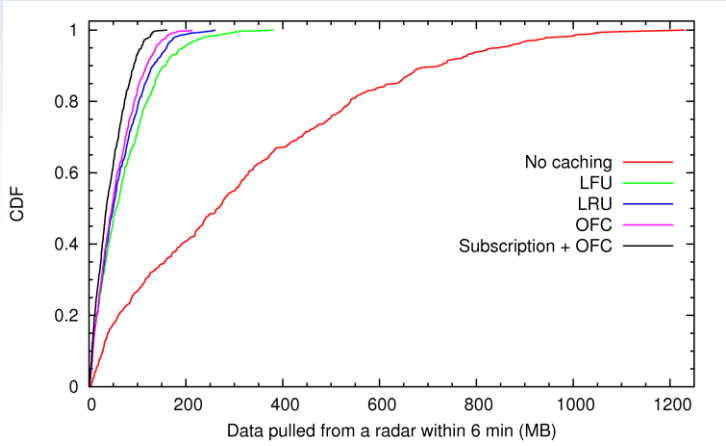
NDN for DCAS – Simulation Setup

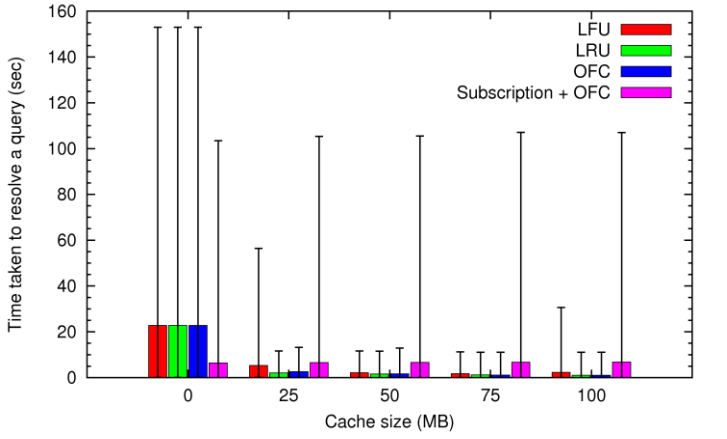
- Parameters from CASA IP1 test bed
  - 121 radars placed on a 300 km x 300 km area, 30 km apart, 40 km range
  - 30 PPI scans, unsynchronized radars
  - 4 bytes per data type per tile (tile 100 m x 100 m)
  - 5 proxies, 16 x 2 reflectivity & velocity, & 4 x 3 NBRR, nowcasting, & QPE
  - 1 Gbps links
- Reflectivity data from a large-scale weather event over Oklahoma
  - 05/23/2011 10:00pm to 05/24/2011 2:00am
  - AOI – Active weather if reflectivity ≥ 25 dBz
  - End users – 2 NWS, 30 EMs, 8 researches, & 20 media

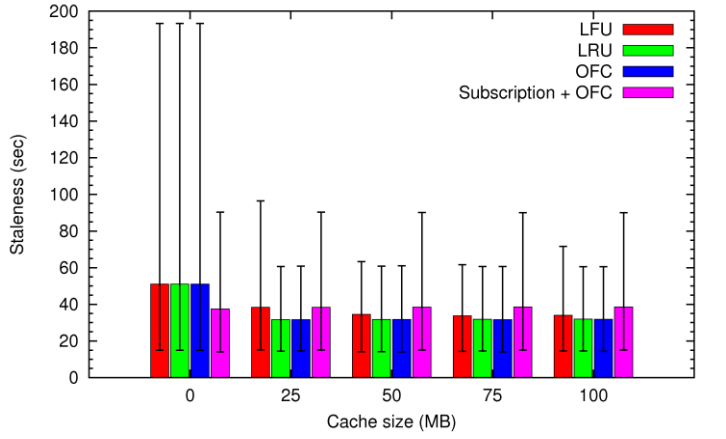


NDN for DCAS – Performance Analysis









- Bandwidth requirements are reduced
  - Subscription scheme – 61%, Oldest First Caching (OFC) – 87%
  - Better load distribution
- Better quality data – Waiting time & staleness is reduced
  - Waiting time – 88%, Staleness – 69%

Summary & Future Work

- Multi-user, multi-application, & multi-sensor DCAS system implemented on top of an overlaid NDN
- Reduce resource requirements & enhance quality
  - Enable bandwidth reduction & load balancing
  - Reduce response time & staleness
- Significant performance gains → Applicability of NDN for other DCAS systems

- Aggregate data from heterogeneous sensors in NDN
  - Integrate other sensors & enhance event-specific queries
  - Supporting event specific queries
    - "*find all locations where wind speed is 60 km/h or higher*"
  - Reference implementation based on CCNx

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Questions/Comments

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