CNS: Content-oriented Notification Service for Managing Disasters

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"Modern" Disasters & Disaster Management

- Multiple incidents occurring in different places around the same time
  - London Bombing July 7th, 2005
    - 8:50 a.m. eastbound Circle Line train #204 Aldgate
    - 8:51 a.m. westbound Circle Line train #206 Edgware Road
    - 8:53 a.m. southbound Piccadilly Line train #311 King's Cross
    - 9:47 a.m. #30 bus Tavistock Square
  - Kaohsiung gas explosion (2014), Nepal earthquake (2015), …
- Need for collaboration *within and between* emergency services
  - Cross-functional collaboration
    - **Normal first responders:** Police, Ambulance, Fire brigade, Hospital, …
    - **Others:** People/team with special expertise (e.g., Underground Control Center)
  - Collaboration across administrative and management boundaries
- Dynamically created special teams of first responders with complementary expertise
  - New administrative hierarchy
- Timely and efficient communication is critical

We believe it is important to shift the focus on disaster communication from being an afterthought to being a first class citizen, exploiting emerging network architectures. Effective, convenient and timely communication could result in better outcomes, including fewer casualties.

Problems with Existing Communication Platforms

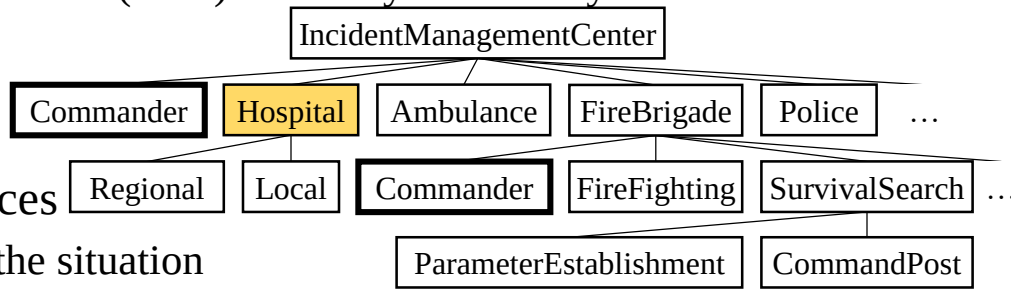
- Message sender/caller needs to know the specific individuals and their ID (IP/phone #)
  - Management overhead: a (manual) mapping between the roles and the individuals, IDs
  - Messages cannot reach the right people
    - E.g., London Underground Control Center made calls to the emergency services at 8:59. Nonetheless, the calls did not result in the immediate dispatch of emergency services to the scene.
  - Confusion & misunderstanding about the situation
    - E.g., The first responder services in London Bombing still sent units to the wrong places.

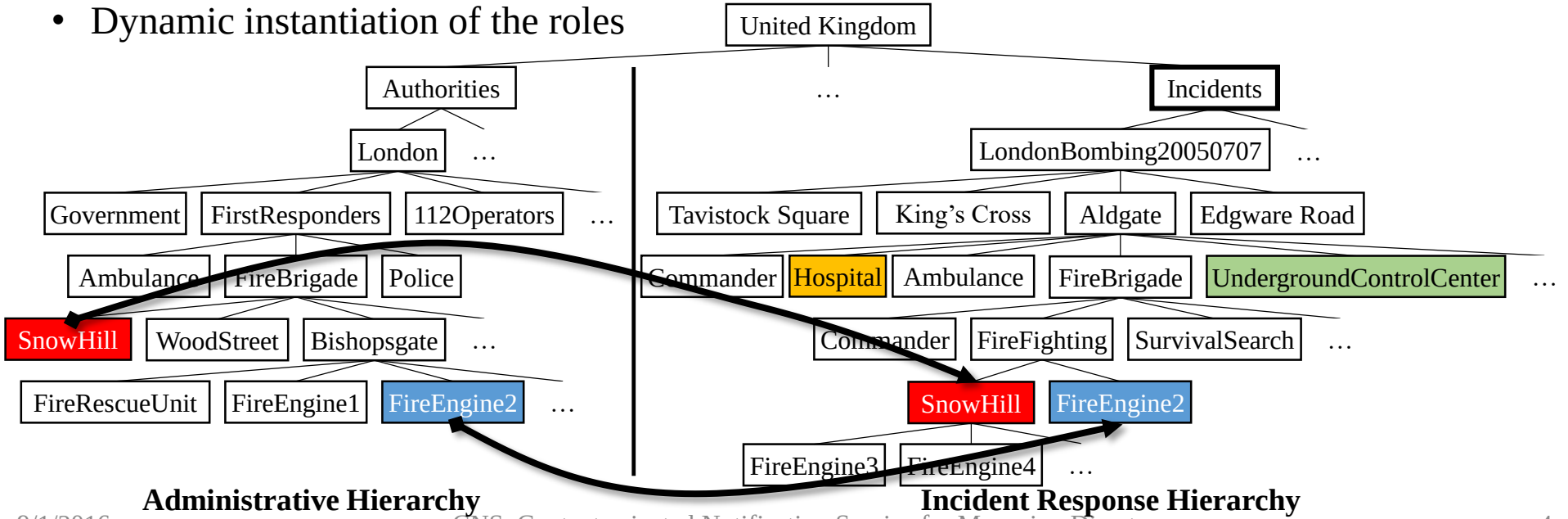
- Lack of communication among the dynamically created 'special teams'
  - Lack of role to ID mapping
  - Emergency management traffic has to share the already-congested civilian channel
    - Difficult to use specialized channel because of need for collaboration across administrative boundaries
  - Difficult to correct for errors (redeployment) once the units are mobilized

- Difficult to share information in a timely and efficient manner
- These problems result in delayed response and poor outcomes for disaster management

Design of CNS – Naming Schema & Disaster Templates

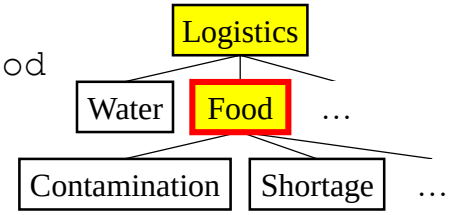
- Naming schema that can be used for normal communication and disaster management
  - Using hierarchical structure helps to match the real-world command chain
  - Administrative hierarchy – for normal communication among first responders
  - **Incident Response Hierarchy** – place holder for disasters
  - First responders listen to (subscribe) the names (roles) once they are on duty
- Disaster templates
  - Preplanned namespaces for disasters
- Dynamic installation of disaster namespaces
  - The namespace can evolve according to the situation
- Dynamic instantiation of the roles





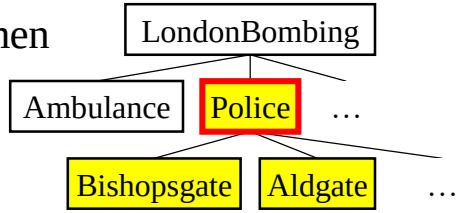
Design of CNS – Recipient Hierarchy

- Consider a publish/subscribe scenario (recall our work on COPSS)
- Content hierarchy example:
  - When a sender sends a message (publication) related to `/Logistics/Food`
  - The publication will reach subscribers of prefix `/Logistics` and `/Logistics/Food`
  - Subscribers subscribing to prefix `/Logistics/Food/Contamination` will not receive the publication according to the longest prefix matching
  - It is fine with content hierarchy as first responders dealing with `/Logistics/Food/Conta…` may only wish to deal with contamination, rather than other problems (e.g., food shortage)



Content Hierarchy

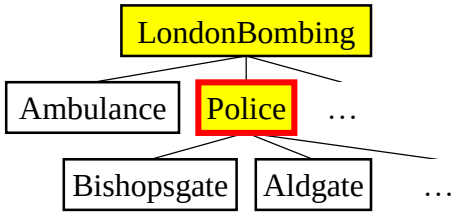
- Recipient hierarchy example:
  - When a commander wants to send a message (publication) to all policemen dealing with London Bombing, he will use the prefix `/LondonBombing/Police`
  - The publication should reach first responders subscribed to `/LondonBombing/Police` and `/LondonBombing/Police/*`
  - This is an important communication paradigm for efficient disaster management, but not achievable with longest prefix matching



Recipient Hierarchy

Design of CNS – What if we do not have recipient hierarchy?

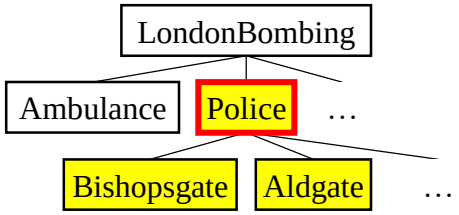
- What if we use traditional content hierarchy for delivering to a number of recipients?
  - E.g., A police commander dealing with London Bombing, subscribes to `/LondonBombing/Police`
    - He will receive messages that are sent to `LondonBombing/Police/Bishopsgate`, …/`Aldgate`, etc.
    - But he will only receive a subset of messages meant to reach all personnel dealing with London bombing: i.e., won't receive msg sent to (`/LondonBombing`)



Content Hierarchy

  - To ensure he receives everything sent to `/LondonBombing` and to avoid receiving messages sent to individual responders, he has to:
    - Create a new name just for himself to avoid getting messages to `Bishopsgate`, `Aldgate`, etc.
    - Subscribe explicitly to `/…/LondonBombing`, `/…/Incidents` (and each and every name above in the hierarchy)
  - No longer taking advantage of the hierarchy any more:

    will be the case for each individual role: subscribe to individual names
    - This places an unnecessary burden on individuals/first responders



Recipient Hierarchy

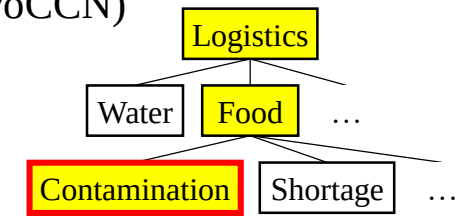
- Recipient Hierarchies help in this context.

- We note: ***Both*** content hierarchy *and* recipient hierarchy are needed for dealing with disaster management

Design of CNS – Recipient Hierarchy & Query-Response

- How can recipient hierarchies help with query-response (i.e., interest-data) interactions?
  - Example: VoCCN

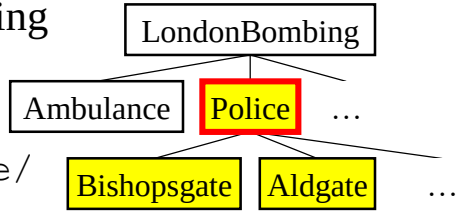
- Content hierarchy example:
  - When a victim encounters food contamination in a disaster, he will call (VoCCN) a specialist for this, using prefix `/Logistics/Food/Contamination`
  - The first Interest packet of the call should reach anyone dealing with (i.e., serving prefix) `/Logistics/Food/Contamination`, or specialist dealing with (serving prefix) `/Logistics/Food` or `/Logistics`
  - This works fine with longest prefix matching (i.e., content hierarchy)



Content Hierarchy

- How can Recipient hierarchy help?:
  - When a victim wants to call any policeman that deals with London Bombing
  - This first Interest packet should reach the police commander (who is serving prefix `/LondonBombing/Police`), or a Bishopsgate police person dealing with London bombing (serving `/LondonBombing/Police/Bishopsgate`), or an Aldgate police dealing with London Bombing, …
  - With recipient hierarchies, the network expands the name to the lower levels

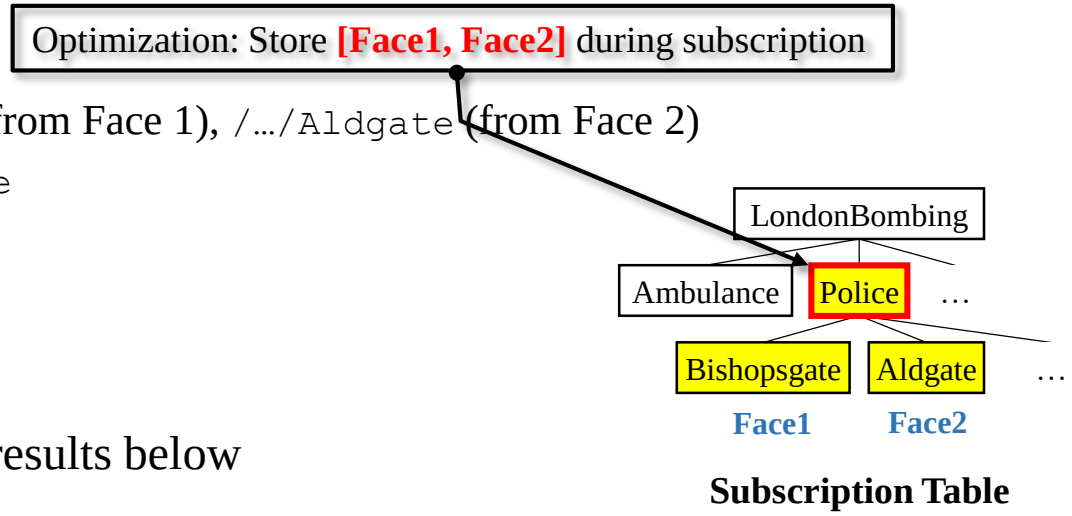
  of the hierarchy, instead of just stopping at doing longest prefix match



Recipient Hierarchy

How can the Network support Recipient hierarchies?

- Have a flag in the packet to distinguish the use of different hierarchies
- Use longest-prefix match for content hierarchy
- For recipient hierarchy, the router would
  - Iterate through all the sub-nodes of the name in the packet
  - Forward the packet to all the outgoing faces in the subtree
  - Optimization: store the outgoing faces of its subtree on each node
- Consider an example:
  - 2 subscriptions: `/…/Bishopsgate` (from Face 1), `/…/Aldgate` (from Face 2)
  - Message: `/LondonBombing/Police`
- Overhead: < 2% (forwarding latency)
- Benefit: let us look at our evaluation results below

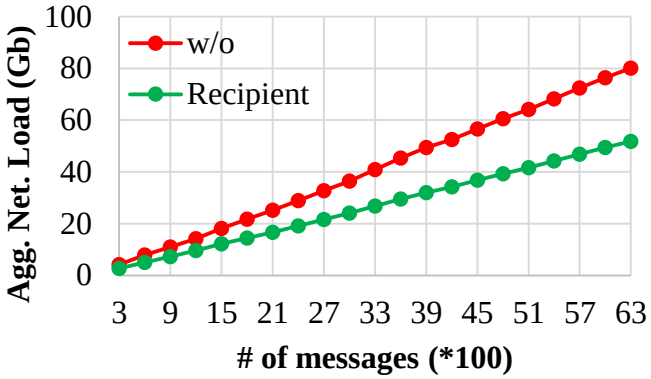


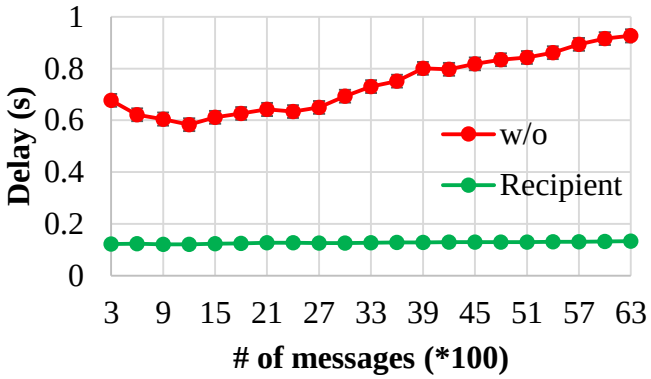
Design of CNS – Attribute-based Prioritization

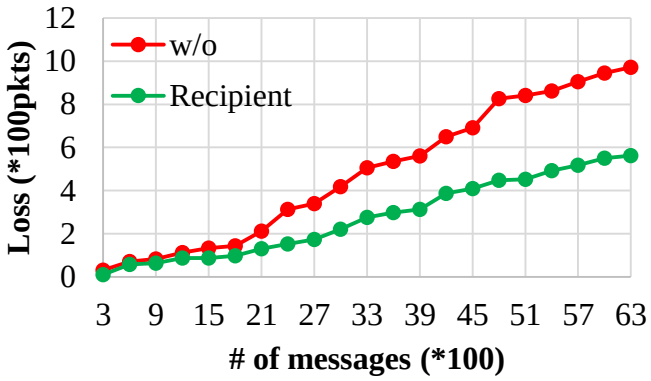
- First responders usually have to use the civilian channel for cross-department collaboration
- Civilian channel is extremely congested because of citizens seeking to communicate with one another to convey and enquire about their well-being and location
- ACCess OverLoad Control (ACCOLC) allows authorities with special devices to communicate on civilian channel while *blocking* all the civilian traffic. But, issues arise:
  - Authorities without special devices cannot communicate
  - Can cause public panic
- A system based on logical prioritization is desirable
- Prioritization should be decoupled from the receiver of a message
  - Same destination can receive messages of different types (priority)
  - Coupling name and prioritization will cause the name hierarchy to be duplicated for each priority
  - Neither convenient, nor efficient
- We add an attribute field in the packet header to indicate the priority of the message
  - Attribute can be added/suggested by the applications automatically
  - **Use signatures for authentication and prevent misuse of priority attributes**
    - Content validated when entering the network (more efficient than forward and discard)
  - The attribute can also be used to alter the forwarding rules
    - E.g., a “local-broadcast” attribute to enable civilians call for help from nearby civilians/first responders

Evaluation – Lab Testbed Emulation

- Lab testbed – Emulation
- Topology
  - 6 physical machines
  - 100 Mbps links and 10ms delay
- Namespace
  - Recipient hierarchy with 3-level quad tree
  - Each name has 3 subscribers
- Message trace
  - 6300 messages
  - 1-99 pkts per message (500 bytes per pkt)
- Mobility trace
  - Random movement (uniform dist. Interval: 2-120s)
  - 4390 reconnections in 70min
- Results show that recipient hierarchy has:
- Less network traffic (multicast w/hierarchical structure)
- Lower delay (fewer packets, less queueing)
- Lower packet loss (better aggregate subscribers)







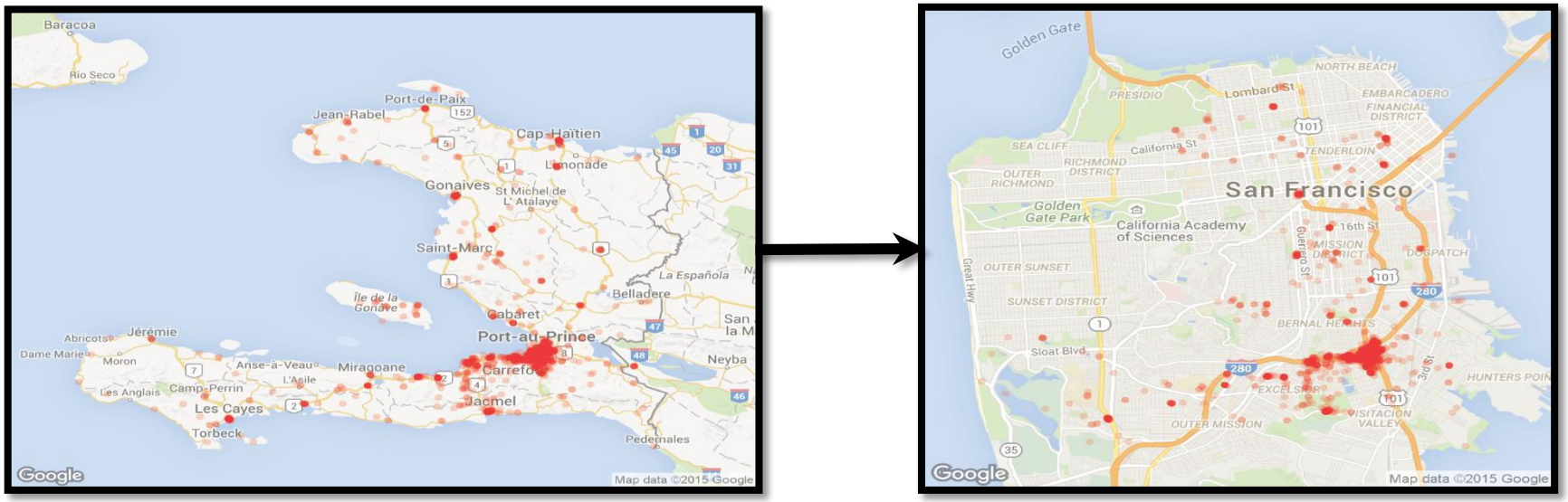
Evaluation – Large Scale Trace-Driven Simulation

- Large scale simulation based on traces
- Namespace
  - Extracted from dataset of messages exchanged during the Haiti earthquake of 2010
  - Original dataset is based on categories – matches a content hierarchy
  - Used as both content and recipient hierarchy

Name	# of Msgs.	# of Pkts.	Name
AllCategories	0	0	/
1. Emergency	335	2158	/1
1b. Medical Emergency	199	1678	/1/1
1c. People trapped	166	902	/1/2
1d. Fire	5	30	/1/3
2. Vital Lines	396	3467	/2
2a. Food Shortage	1388	13123	/2/1
2b. Water shortage	1171	10785	/2/2
2c. Contaminated water	9	83	/2/3
2c. Security Concern	12	99	/2/4
2d. Shelter needed	289	2937	/2/5
2e. Fuel shortage	20	186	/2/6
2f. Power Outage	12	111	/2/7
3. Public Health	0	0	/3
3c. Medical equipment and supply needs	284	2758	/3/1
4. Security Threats	64	639	/4
4a. Looting	22	164	/4/1
4e. Water sanitation and hygiene promotion	192	1571	/4/2
5. Infrastructure Damage	0	0	/5
5a. Collapsed structure	136	910	/5/1
5b. Unstable Structure	31	209	/5/2
5c. Road blocked	28	169	/5/3
6. Natural Hazards	1	7	/6
6a. Deaths	2	9	/6/1
6b. Missing Persons	17	117	/6/2
6c. Asking to forward a message	7	79	/6/3
6c. Earthquake and aftershocks	15	160	/6/4
7. Services Available	283	2139	/7
7a. Food distribution point	275	2209	/7/1
7b. Water distribution point	3	20	/7/2
7c. Non-food aid distribution point	68	657	/7/3
7d. Hospital/Clinics Operating	241	1718	/7/4
7g. Human remains management	37	331	/7/5
7h. Rubble removal	7	51	/7/6
8. Other	127	920	/8
8d. Recherche et sauvetage | Search and Rescue	48	352	/8/1

Evaluation – Large Scale Trace-Driven Simulation

- Large scale simulation based on traces
- Namespace
  - Extracted from Haiti earthquake dataset of 2010
  - Original dataset is based on a categorization -> content hierarchy
  - Used as both content and recipient hierarchy
- Message trace
  - Haiti earthquake dataset: Lat/Lng, but didn't have any mobility information
  - Compressed the 3K messages into 1 hour
  - Translate location of messages to San Francisco, leveraging another dataset (to represent movement of first responders)



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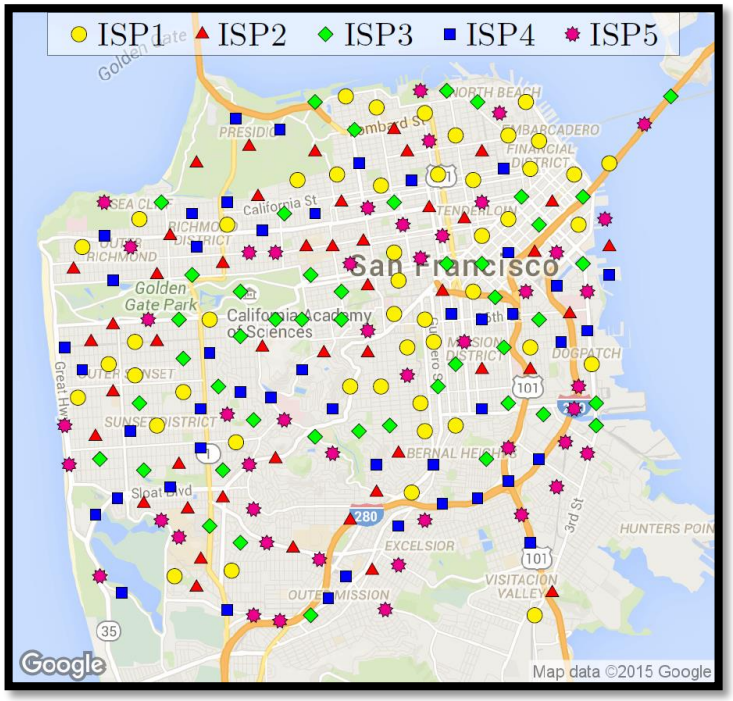
- Topology
  - Access points in San Francisco
  - 5 overlapping ISPs each has 5 domains



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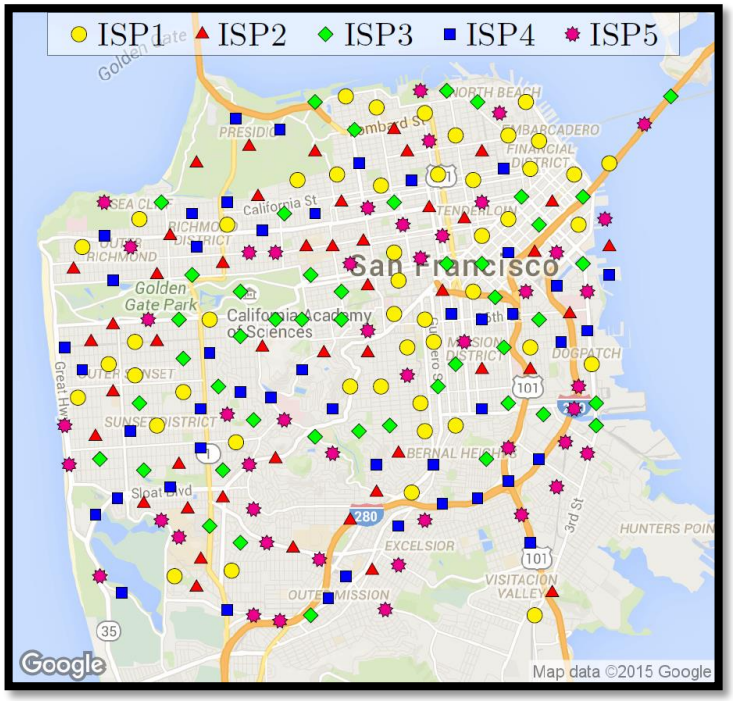
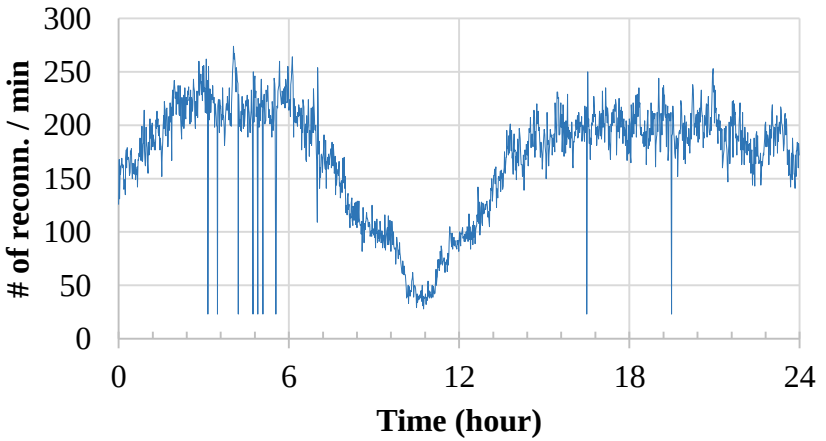
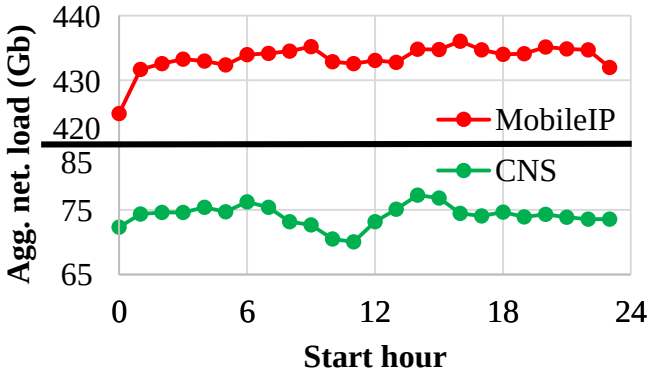
  - 5 overlapping ISPs each has 5 domains
- Mobility trace
  - Cab movement in San Francisco
  - Trajectory of 494 cabs on 2008/5/28
  - Simulation based on the message trace for each hour on that day

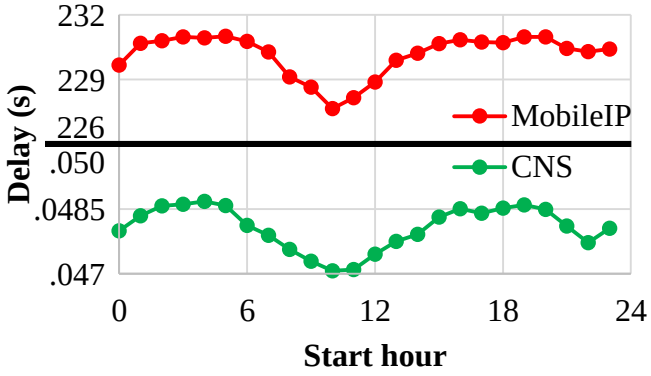


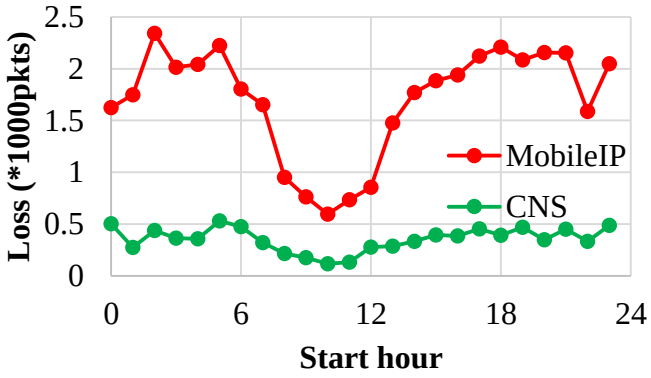


Evaluation – Large Scale Trace-Driven Simulation

- First used Haiti message trace as content hierarchy
- Compare CNS *vs.* MobileIP
- Results show:
  - CNS consumes lower network load since it uses multicast
  - CNS does not see the congestion at the home agents in Mobile IP, therefore has much lower delay
  - CNS sees fewer packet lost due to the benefits of aggregation of Interests using the hierarchical structure
- CNS can also relieve the burden of users having to manually mapping the roles to identities.
- Less effort => more lives saved!

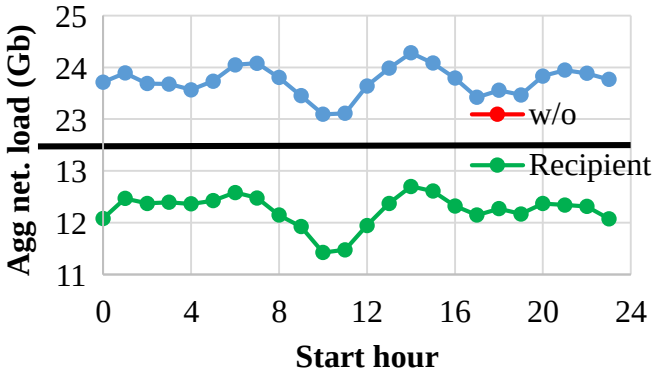


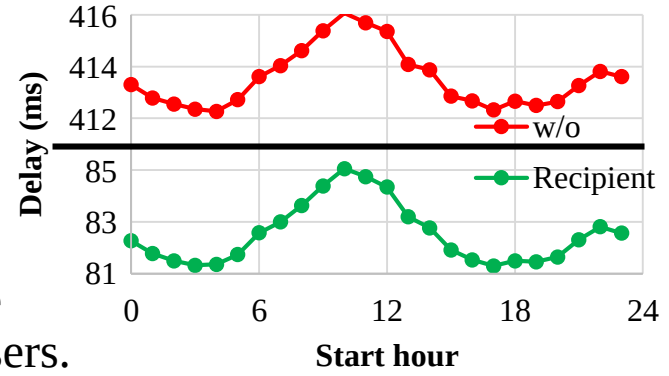


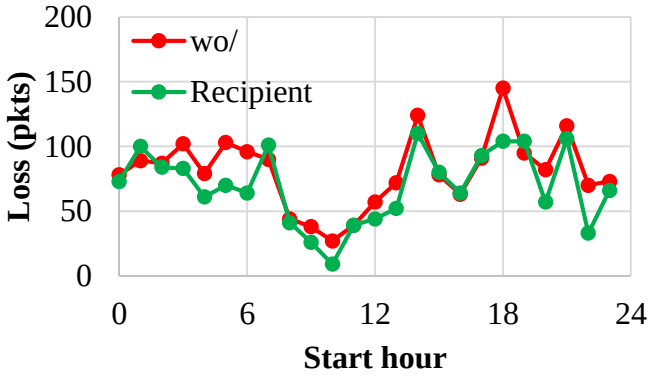


Evaluation – Large Scale Trace-Driven Simulation

- Use the Haiti message trace as recipient hierarchy
- Compare CNS w/ and w/o recipient hierarchy
- Result shows (similar to the testbed emulation):
  - CNS w/ recipient hierarchy consumes less network traffic (hierarchy among recipients)
  - CNS w/ recipient hierarchy sees lower delay (less queueing)
  - CNS w/ recipient hierarchy sees smaller loss (aggregation)
- Users in CNS w/ recipient hierarchy only need to subscribe to one name: more scalable, & reduce the burden on the users.







Conclusion

- Communication is key to managing disasters – timely information to the right people
  - Cross functional, cross administrative boundary cooperation among first responders is needed
  - People who are not first responders might also need to be involved
  - But hierarchy is also important: network enabling efficient communication in a dynamically created new hierarchy is desirable
  - These “special teams” can/usually have to use civilian channel to communicate

- We proposed CNS – Content-oriented Notification Service – to help manage the disasters
  - Use a content-centric network - enables role-based, context-aware communication
  - CNS proposed a naming schema - takes both normal and disaster scenarios into consideration
  - Support for recipient hierarchy
  - Template and dynamic installation of namespaces on seeing a disaster
  - Attribute-based prioritization

- With a lab testbed emulation and large-scale trace-driven simulation, we show:
  - CNS can outperform usual solutions (MobileIP) thanks to the name-oriented communication
  - CNS w/ recipient hierarchy can further reduce network traffic, message delay and packet loss since it can take advantage of the hierarchical structure