ReDiCom: Resilient Communication for First Responders in Disaster Management

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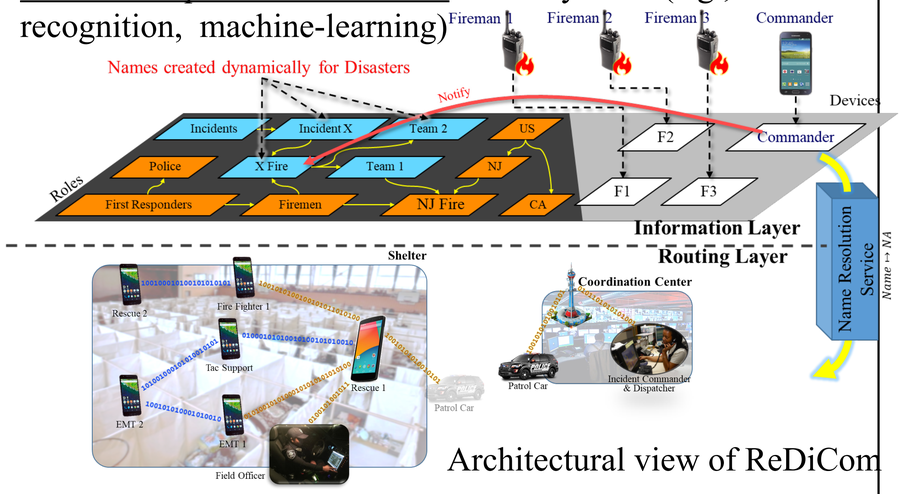
Motivation & Building Blocks of ReDiCom

- **Keys to effective response to an incident**
- Effective communication *within and among* first responder team members: *teams formed dynamically*
- Comm. among law enforcement, emergency, EMT, transport *& other services* and *public;* based on nature & scale of incidents
  - Infrastructure may be impacted: provide *resilience*
  - *Limited computation resources* for heavy tasks (e.g., face recognition, machine-learning)



Architectural view of ReDiCom

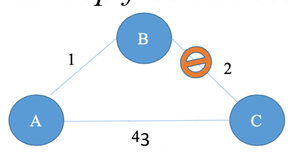
ReDiCom Architecture

- Information Layer
  - Supports dynamically formed teams: Graph-based namespace for flexibility; Pub/sub for timeliness
- Network Layer
  - Supports data dissemination: connected and delay-tolerant links
  - Supports data transmission over flat names (identifiers)
- Link Layer
  - Exploit Device-to-Device communication: Complement infrastructure-based communications
- Coded Device-to-Device Computation
  - Distributed computing for first responders with little or no infrastructure support
  - Higher reliability, smaller delay, lower communication cost

Please see page 2 for Consensus Protocol and ReDiCom Implementation

Binary State Distance Vector Routing

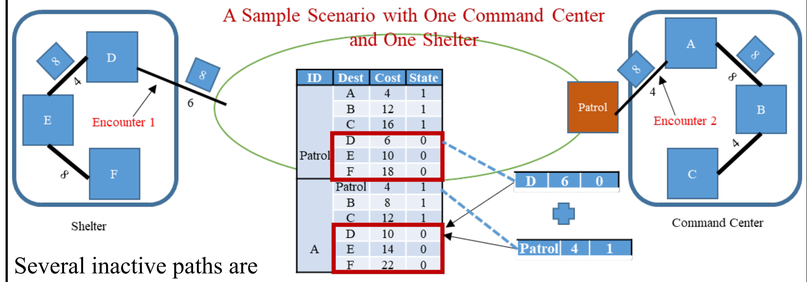
- Conventional *epidemic routing* for DTNs is too costly, causes too many data packet replicas.
- We design Binary State DVRP, a nearly unicast routing that combines:
  - *distance vector* entries with binary state and
  - conventional *epidemic* routing
- A dynamic delay tolerant networking (DTN) routing protocol that:
  - Can work with D2D links (appearing as *TCP-like sockets* to net-layer)
  - Can work with *heterogeneous D2D links* (e.g., Bluetooth or WiFi-Direct)
  - Can handle node *failures* and *resurrections*
  - Is *loop-free* and *scalable*



ID	Dest	Cost	State
A	B	1	1
	C	3	0
B	A	1	1
	C	2	0
C	B	2	0
	A	3	1

State:
0 – Inactive
1 – Active

Two types of **DVT** entries, **active** and **inactive**, for constructing **FT**: active for current paths, inactive for paths that were complete in the past.



ID	Dest	Cost	State
Patrol	A	4	1
	B	12	1
	C	16	1
	D	6	0
	E	10	0
	F	18	0
A	Patrol	4	1
	B	8	1
	C	12	1
	D	10	0
	E	14	0
	F	22	0

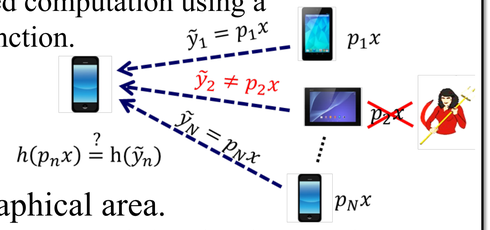
Several inactive paths are installed by nodes at the command center by following binary-state precedence rules. After convergence: (1) Patrol *active-forwards* towards the command center. (2) A, B and C could *inactive-forward* towards the shelter.

Future work

- Enhanced buffering rules on data messages through *priority queues* based on forming a precedence rule
- ID-based group separation for aggregation in tables

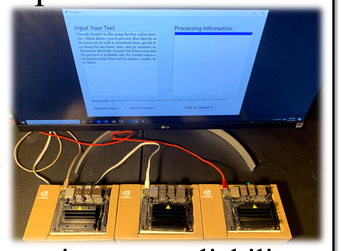
Coded Computation & Communication

- Computation:
  - Distributed computing can be crucial in first responder and PSC systems when there is little or no infrastructure support.
  - Our work:
    - *Divide* a computationally intensive task into small subtasks.
    - Offload each subtask to multiple first responder/civilian devices via *coding* to improve resiliency of the system.
    - Develop secure coded computation using a *light-weight hash* function.
- Communication:
  - A group of first responder devices is in the same geographical area. A common content, e.g., crucial voice instructions, can be broadcast over infrastructure-based links. D2D connections and coding improves reliability.



  - Question: which coded packets over each interface?
  - Approach:
    - Convert the problem to a two-layer connected graph (one for cellular, one for D2D).
    - Maximum independent set gives packets and network codes to be transmitted for cellular and D2D.

Demo: Distributed Text-to-Speech



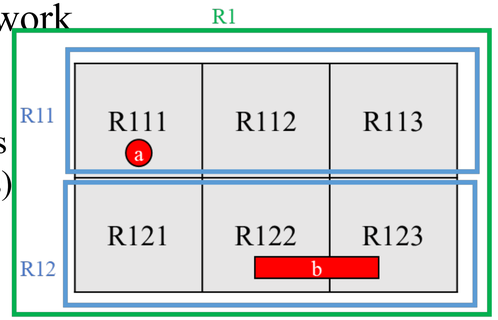
Future work

- Development of coding techniques to improve reliability of our architecture.
- Heterogenous capabilities including varying # of communication interfaces, battery levels & computation power.

Consistent Dissemination using Consensus

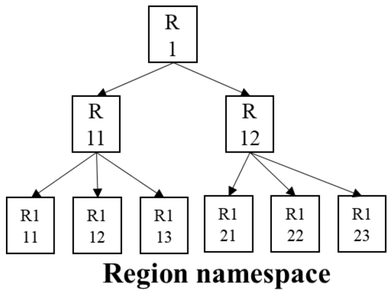
➢ Consistent dissemination in disconnected network

- Delay-tolerant network environment; no network infrastructure or clock synch.
- Application: Map-based geo-tagging for first responders
- Number of mobile users (first responders, commanders) disseminate critical information to each other
  - Updates to a common shared database.
  - Consistency is important and challenging

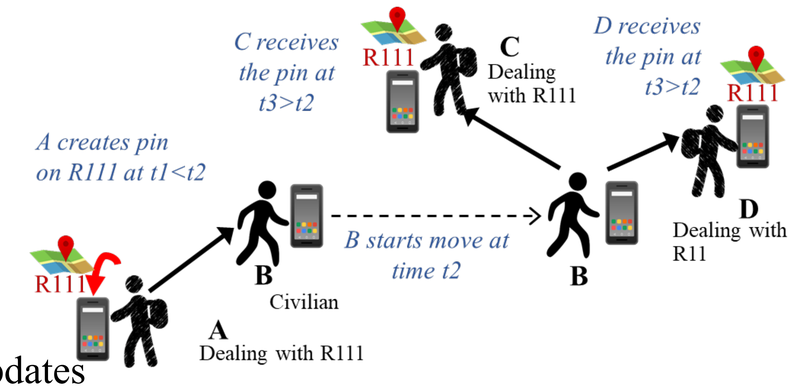


Region-ed map (base + data)

➢ Goal: ensure delivery and consistency of the data across users

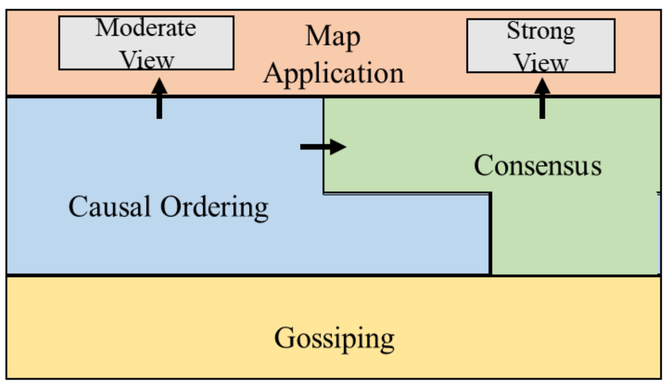


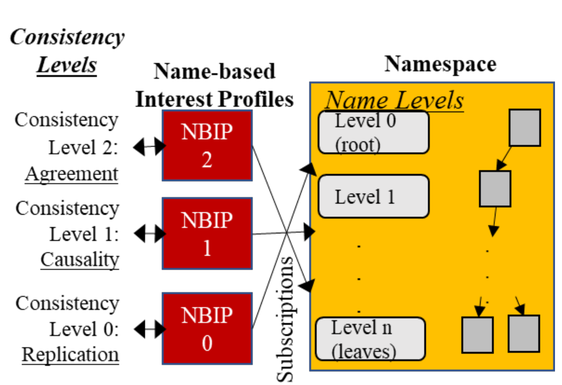
Region namespace



➢ Achieving Consistent Updates

- **Consistency level 0: Replication** – make sure users receive created updates
- **Consistency level 1: Causality** – users get causally ordered view of updates
- **Consistency level 2: Agreement** – users get an agreed upon view of updates Name-based Interest Profile (NBIP) limits each user's participation according to relevant namespace subsets
- Every user has map & namespace offline; Dynamic updates - disseminated consistently
- Consensus –use and enhance One-Third Rule (OTR)-suitable for asynchronous environment



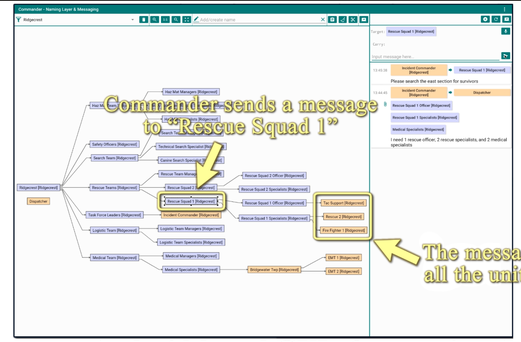


Our method achieves much higher relevant completeness and thus consistency, with much less usage of mobile phone storage

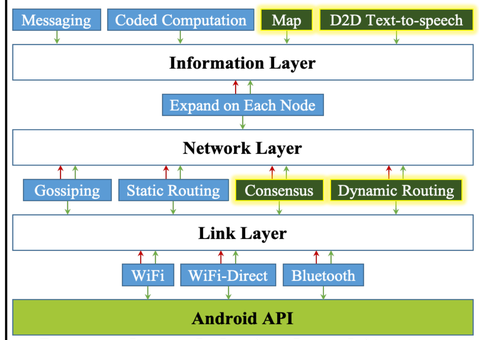
Integration of ReDiCom Capabilities in Implementation

➢ ReDiCom Demo in PSCR'19

- Allow commanders to *dynamically* instantiate templates (preplans)
- Send messages to *different levels* in (and along) the command chain via graph-based namespace
- *D2D* communication *& DTN* for use in infrastructure-less environments



Android-based GUI of messaging App



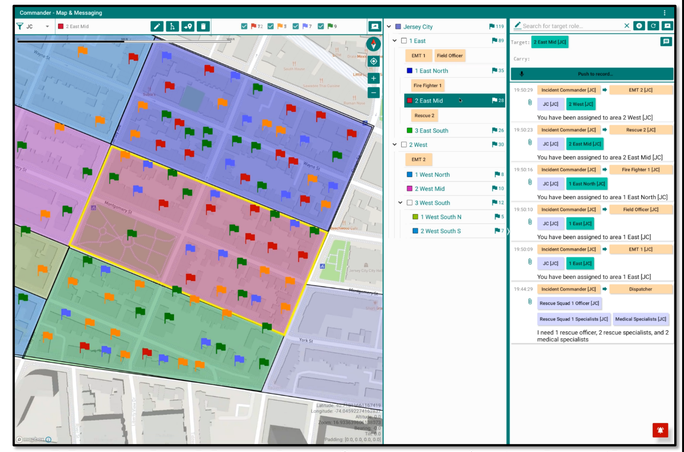
Layered, modularized architecture

➢ Improvements on ReDiCom architecture

- *Modularized* design
  - Enabled different teams develop different components
- Better inter-module communications
  - Remove heavy logic from UI thread, better *responsiveness*
  - *Address dead-lock* issues with RCU & message queue
- New packet library, *avoid copying* between layers
- Android-based GUI, *better stability*

➢ Map tool

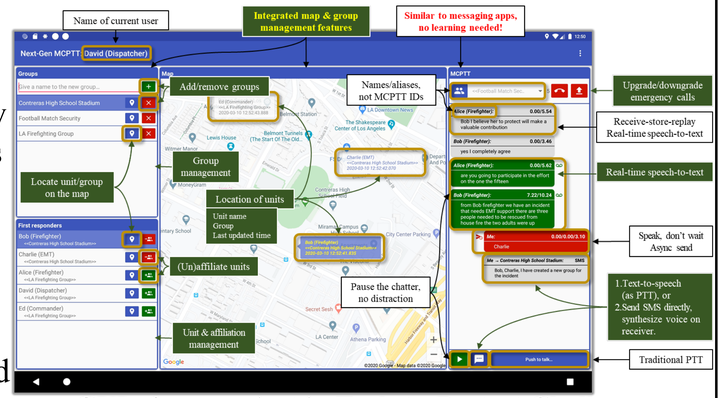
- Create/edit a *hierarchy* of areas
- *Assign units* to areas at different levels
- Add/update markers & send messages *along the location hierarchy*
- Topic hierarchy (markers) & recipient hierarchy (messages) *unified in the graph-based namespace*
- Offline mode (*D2D & DTN* support)



Map tool: add markers & communicate along the location hierarchy

➢ Tech-to-Protect Challenge

- We address 3 issues with MCPTT
  - Messages cannot be stored/replayed
  - Messages cannot be paused, distracting
  - Difficult to synchronize with high latency
- By: (1) storing the messages on the devices for replay & pause, (2) allowing user talk without acquiring a floor, (3) real-time text-to-speech & speech-to-text, (4) map functionality, and (5) other improvements like call prioritization, etc.
- First Prize in NY site; "Superior" award in national contest (best in contest #2)



GUI of our project in Tech-to-Protect Challenge