



A Measurement Study of Network Properties and Protocol Reliability during an Emergency Response

Octav Chipara, William G. Griswold, Anders N. Plymoth, Ricky Huang, Fang Liu, Per Johansson, Ramesh Rao, Theodore C. Chan, and Colleen Buono



Motivation

TRIAGE TAG

Personal Property Received: [] Release Date: []

Patient Name: []

Age: [] Sex: []

Respiratory Rate: []

Capillary Refill: []

Follows Commands: []

Triage Status: []

CONTAMINATED

MORQUE

IMMEDIATE

DELAYED

MINOR

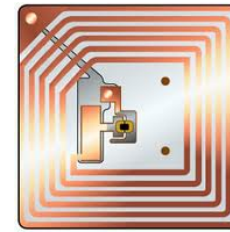


Handwritten Triage Log

Patient ID	Age	Sex	Respiratory Rate	Capillary Refill	Follows Commands	Triage Status
1	25	M	12	< 2s	Yes	Immediate
2	30	F	15	< 2s	Yes	Immediate
3	20	M	10	< 2s	Yes	Immediate
4	35	F	18	< 2s	Yes	Immediate
5	28	M	14	< 2s	Yes	Immediate
6	32	F	16	< 2s	Yes	Immediate
7	22	M	11	< 2s	Yes	Immediate
8	38	F	19	< 2s	Yes	Immediate
9	24	M	13	< 2s	Yes	Immediate
10	31	F	17	< 2s	Yes	Immediate
11	26	M	12	< 2s	Yes	Immediate
12	33	F	18	< 2s	Yes	Immediate
13	21	M	10	< 2s	Yes	Immediate
14	36	F	19	< 2s	Yes	Immediate
15	23	M	11	< 2s	Yes	Immediate
16	34	F	17	< 2s	Yes	Immediate
17	27	M	13	< 2s	Yes	Immediate
18	37	F	20	< 2s	Yes	Immediate
19	25	M	12	< 2s	Yes	Immediate
20	39	F	21	< 2s	Yes	Immediate



State-of-practice



11:29 am Provider

Patient ID: Hy Peer ID: 20

New Patient Patients START

Immediate

Delayed

Minor

Morgue

Age/Sex/Resp/Comm Status

1:0 D:0 M:1 X:0 7:0 Total:1

11:29 am Provider

Patient ID: Hy Peer ID: 20

New Patient Patients START

Age: Adult Child Infant

Sex: Male Female

Respiratory Rate: < 30 > 30

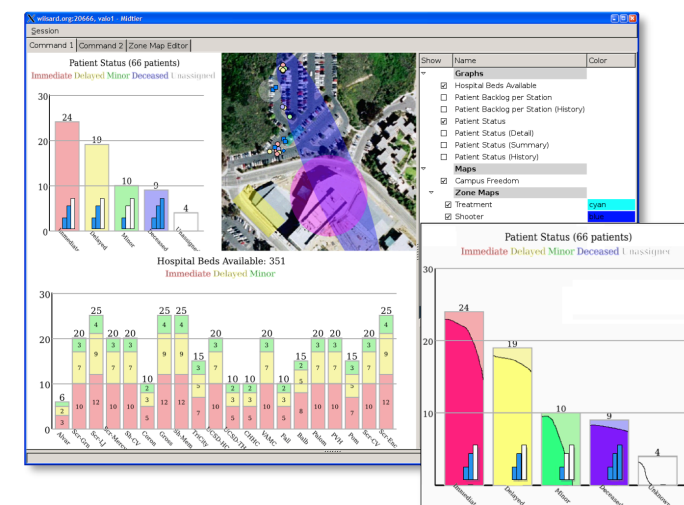
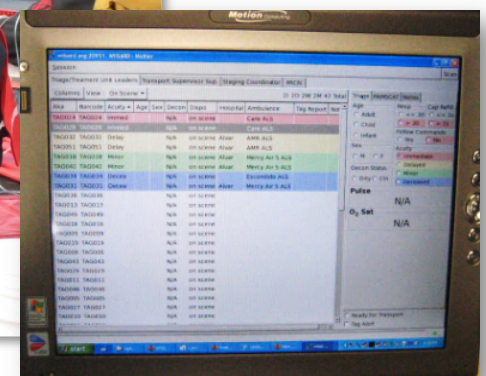
Capillary Refill: < 2s > 2s

Follows Commands: Yes No

Triage

Age/Sex/Resp/Comm Status

1:0 D:0 M:1 X:0 7:0 Total:1

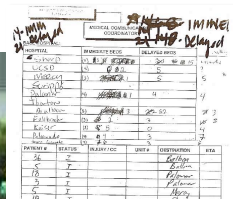


WIISARD

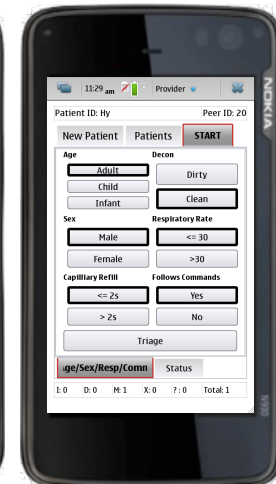
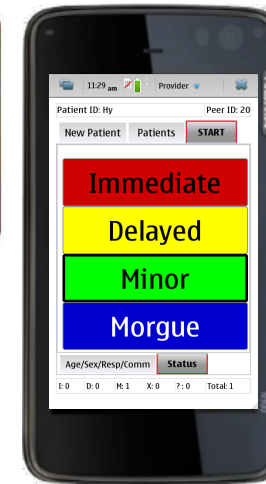
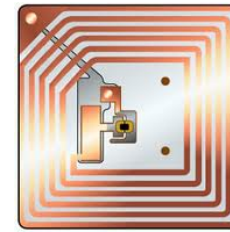
Motivation



A triage tag form with sections for Patient Information, Triage Status, and Mortality. It includes a 'CONTAMINATED' warning on the left and right sides. The form is divided into 'IMMEDIATE', 'DELAYED', and 'MINOR' categories, each with a corresponding color-coded box (red, yellow, and green respectively). It also includes a 'MORGUE' section at the bottom.



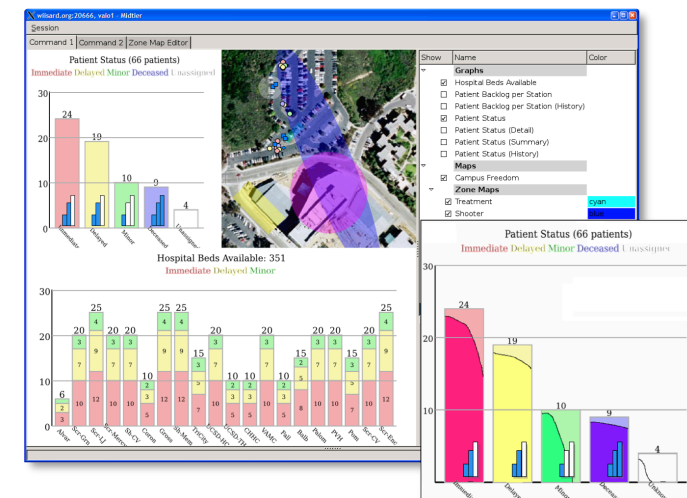
A handwritten triage log with columns for Patient ID, Name, Status, and Location. It contains several entries, some with handwritten notes like 'IMMEDIATE' and 'DELAYED'.



Fundamental Challenge:
Reliable communication in dynamic and disconnected networks



State-of-practice



WIISARD

Related work

- **Communication approaches in emergency response systems**

- client-server approaches perform poorly due to the server bottleneck (e.g., initial version of WIISARD)
- multicast and publish-subscribe systems required end-to-end paths (e.g., AID-N, CodeBlue)
- delay tolerant techniques proposed, but not evaluated (e.g., DistressNet)

- **Few deployments of emergency response systems**

- CodeBlue - evaluated the effectiveness of multicast routing, low reliability (20%)

- **This paper:**

- characterize the network properties observed during deployment
- evaluate the feasibility of DTN techniques for emergency response
- complement DTN studies - considering a cooperative workflow

A reliable network architecture

- **Challenges:**

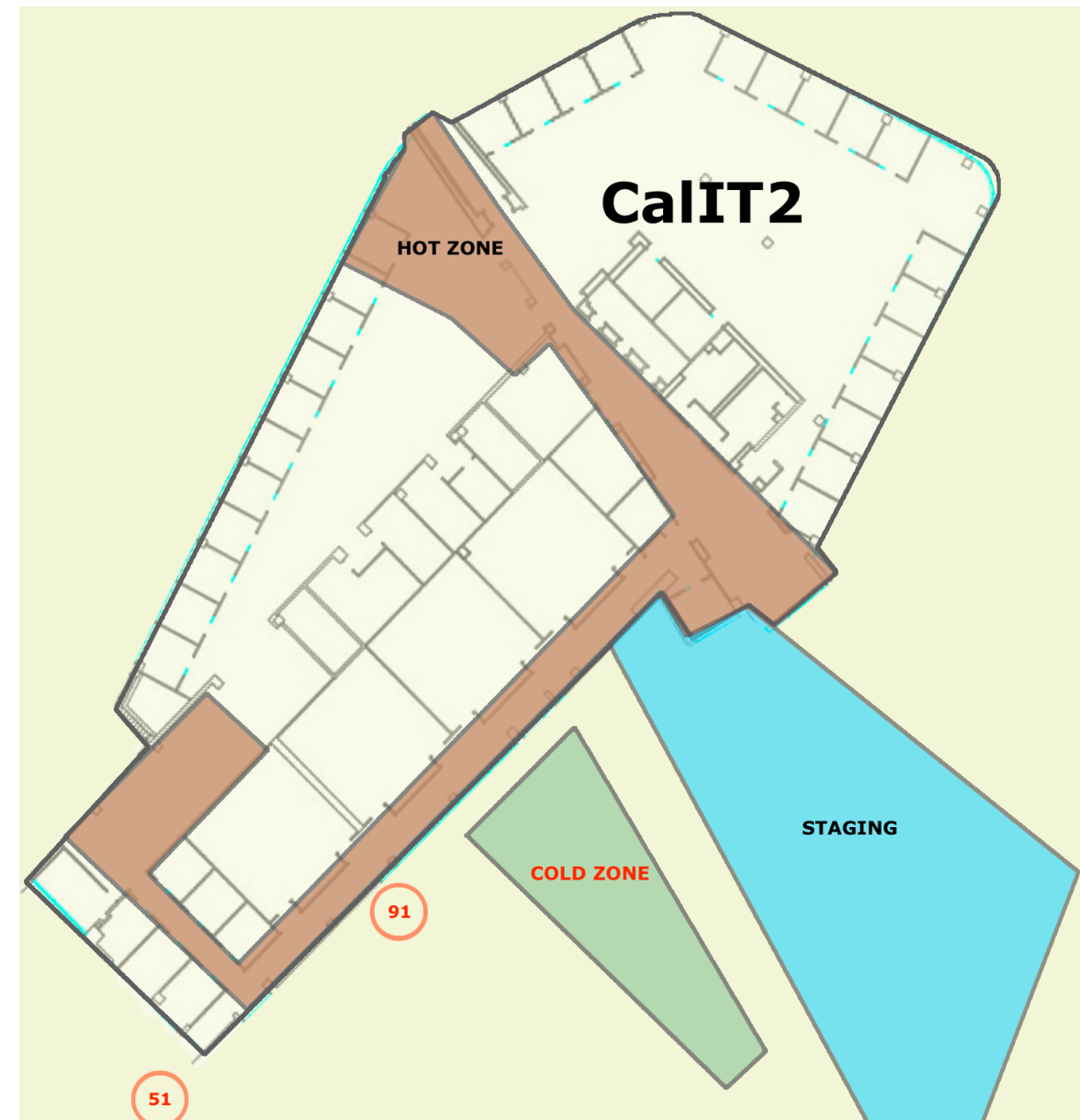
- handle responder mobility
- cope with variations in network properties including network partitions
- minimal reliance on infrastructure

- **Approach:**

- **communication primitive** - simple dissemination to all responders
- **aggressive caching** - sufficient space to store all patient records on all devices
- **gossip based protocol**
 - missing records identified through beacons
 - overhead reduced through suppressing transmission upon overhearing

Deployment

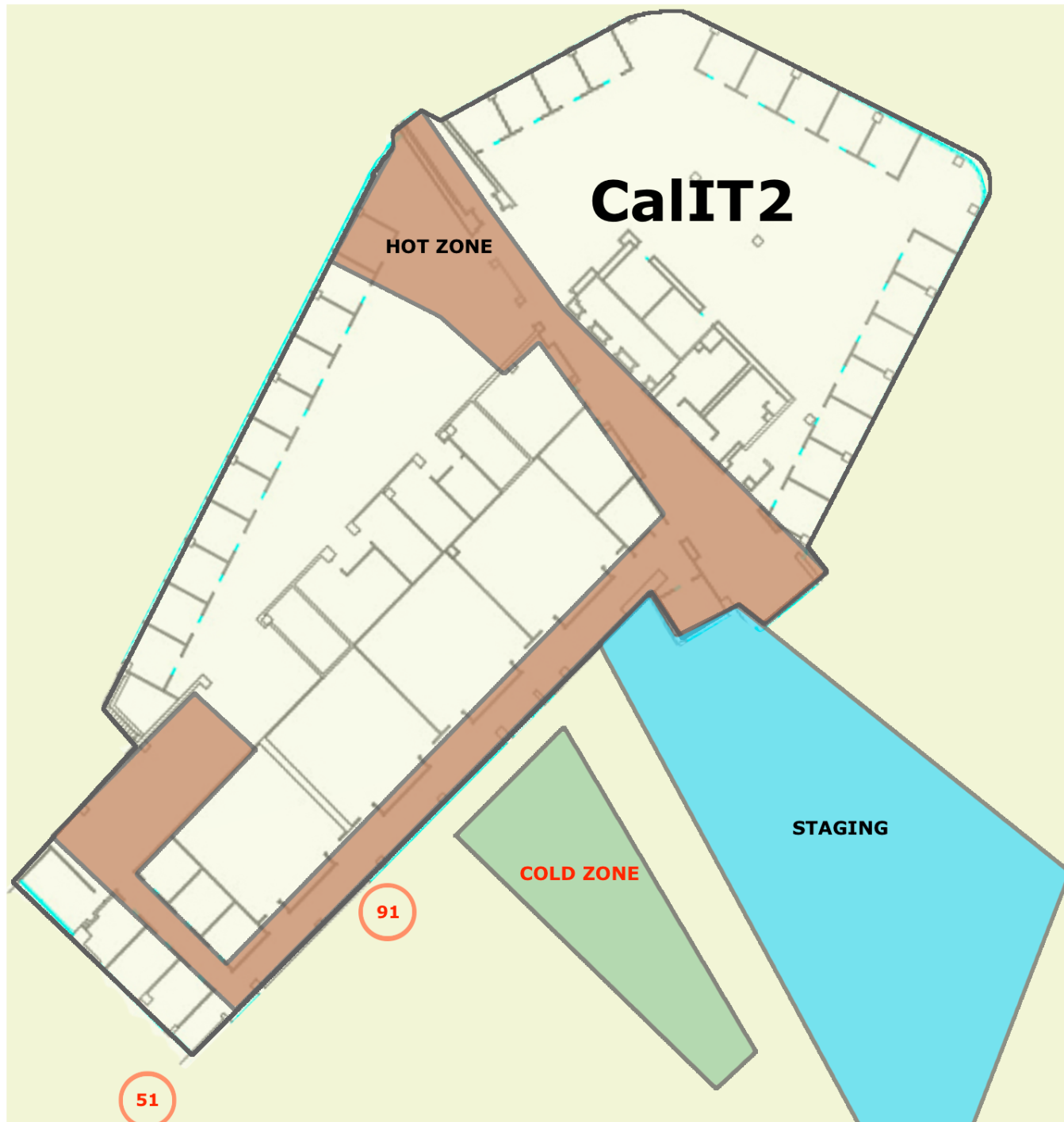
- **Drill exercise at UCSD**
 - 19 responders
 - 41 victims
- **Deployed devices**
 - responders - 16 phones
 - commanders - 3 tablet PCs
- **Time synchronization via NTP**
 - accuracy < 1s



Incident Command Structure (ICS)

Scenario:

Major earthquake ⇒ 41 victims



Incident Command Structure (ICS)

Scenario:

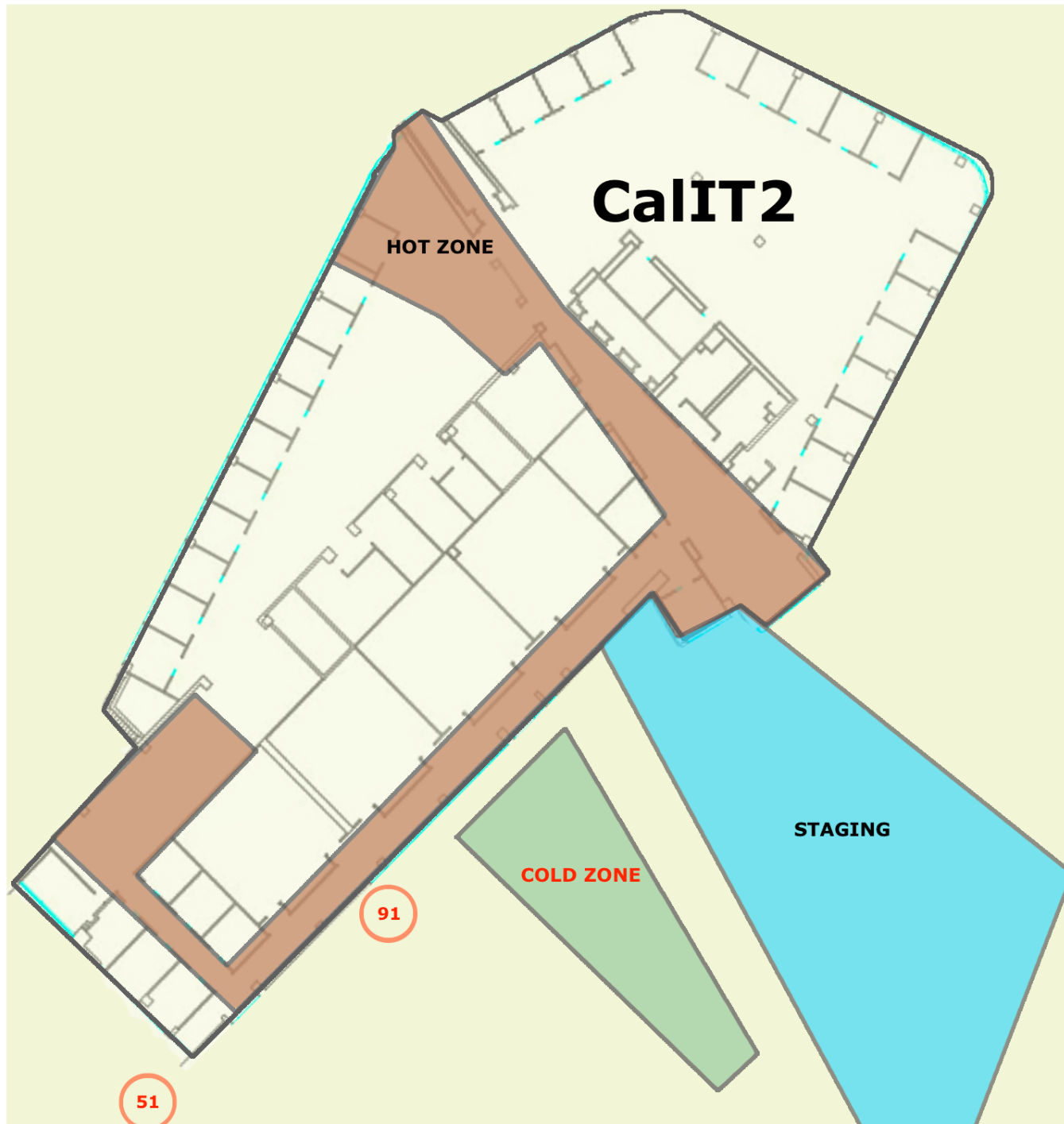
Major earthquake \Rightarrow 41 victims

Staging:

- responders arrive on scene



Incident Command Structure (ICS)



Scenario:

Major earthquake \Rightarrow 41 victims

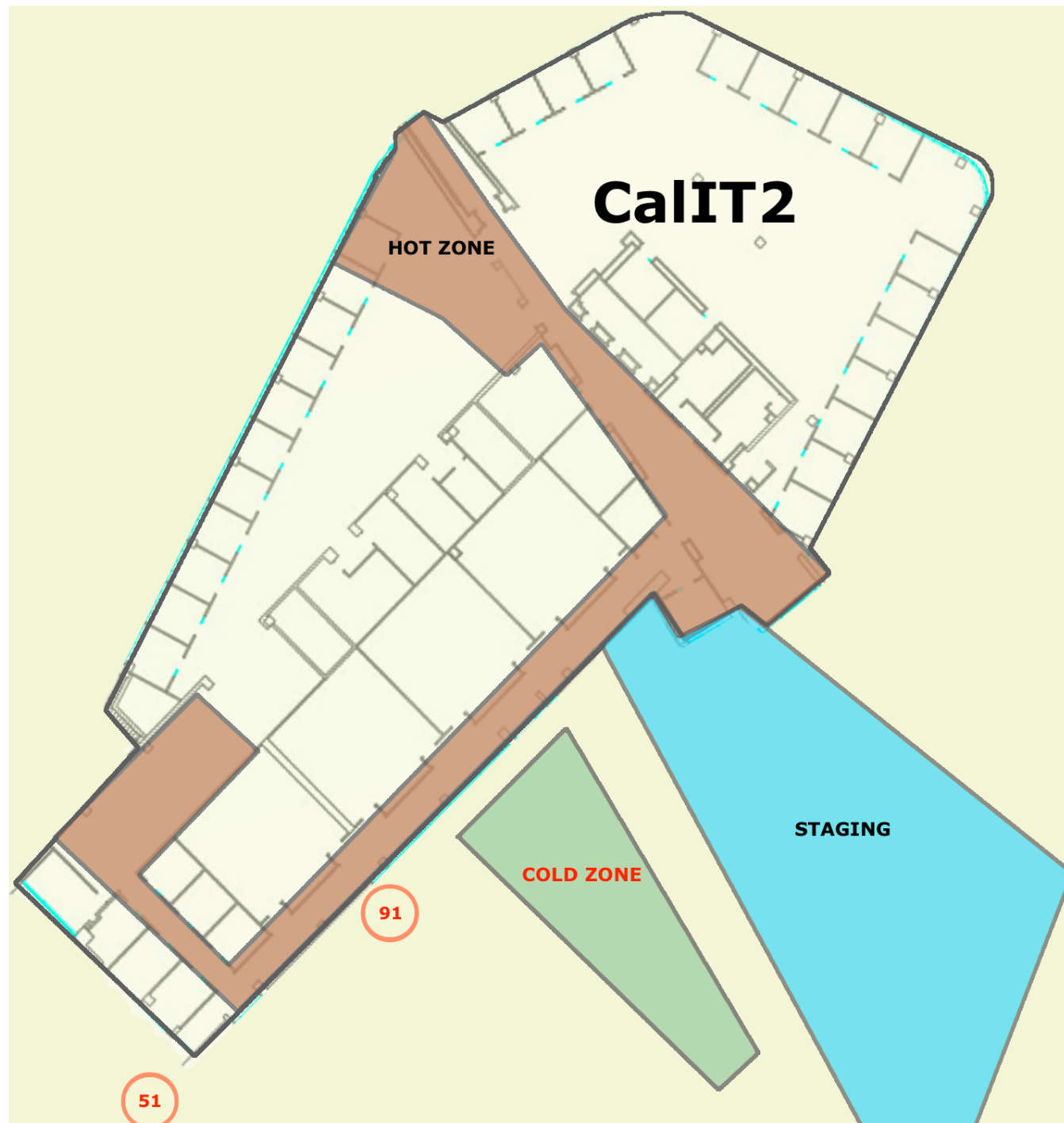
Staging:

- responders arrive on scene

Rescue:

- triage
- provide care
- evacuate

Incident Command Structure (ICS)



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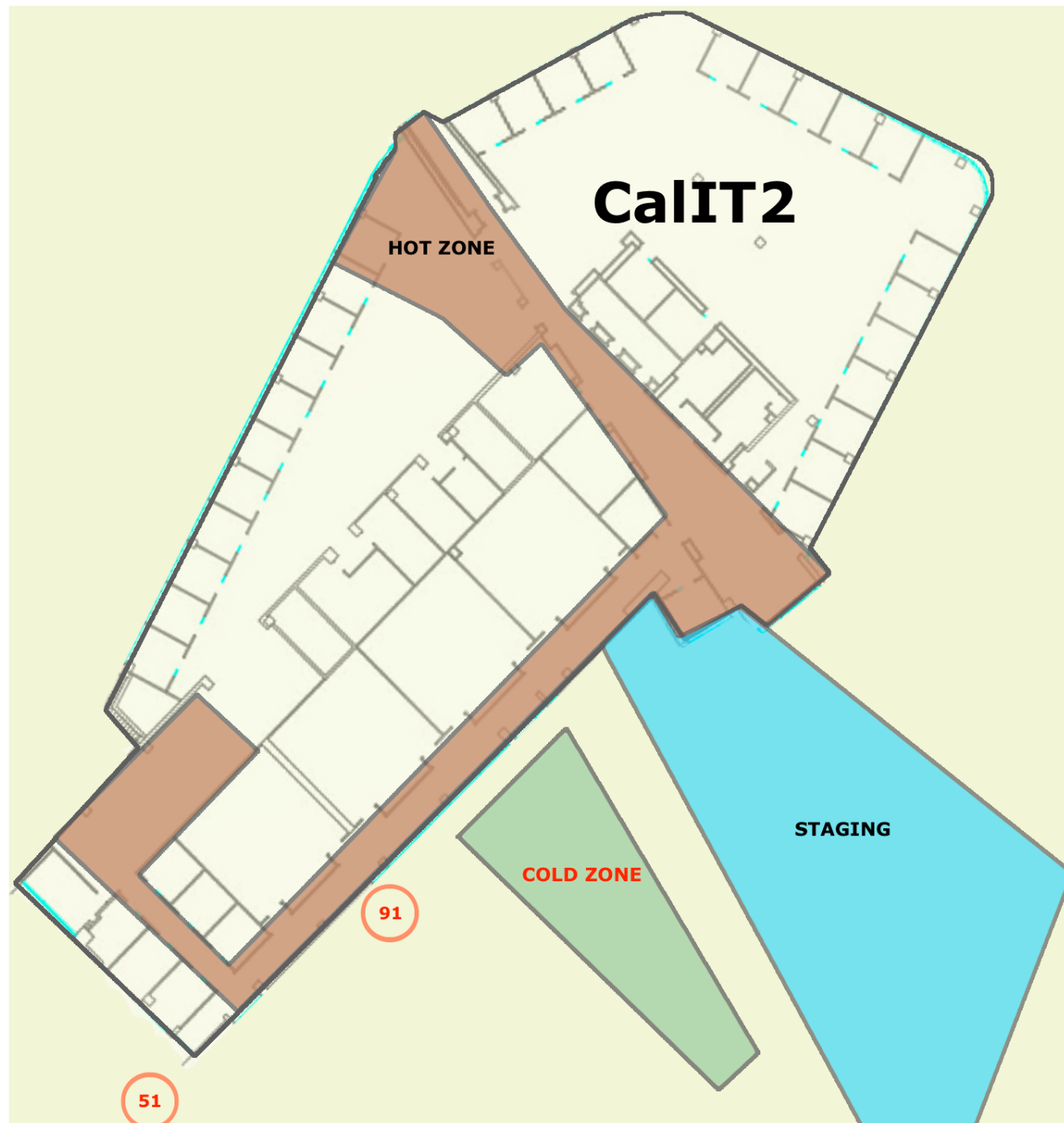
Rescue:

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Treatment:

- re-triage
- provide additional care

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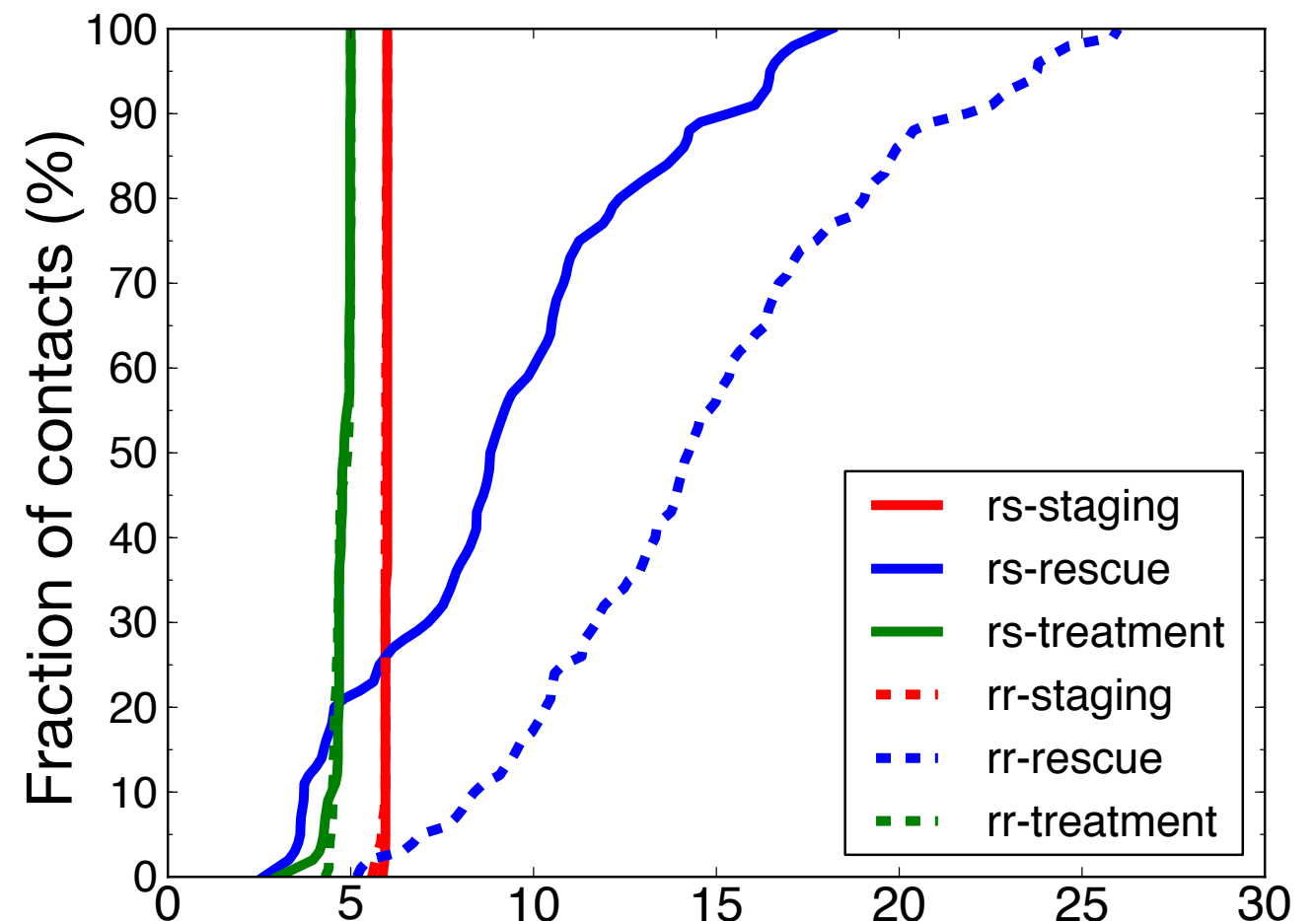
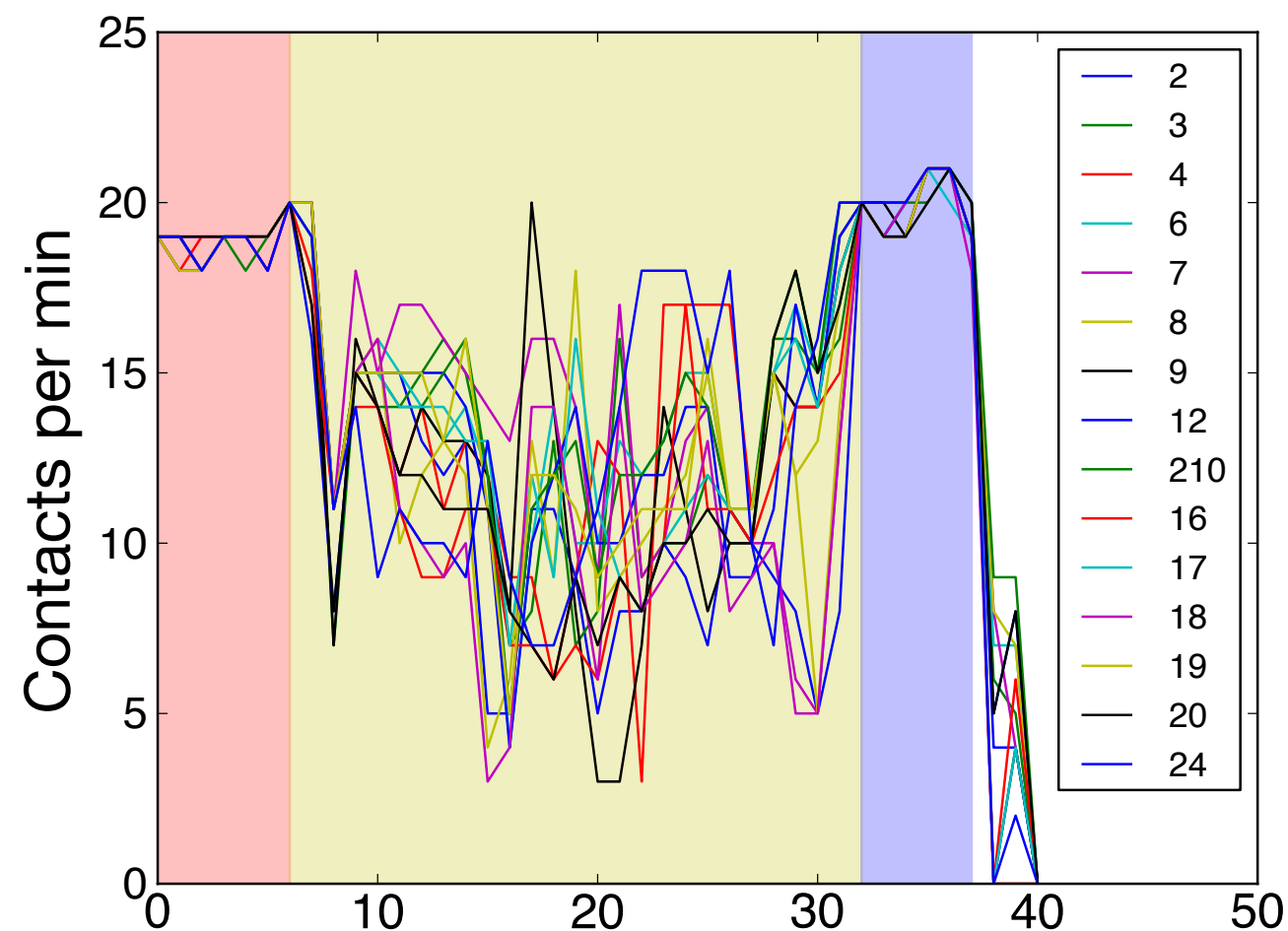
Transport:

- transport to hospitals

Feasibility of DTN-based emergency resp. systems?

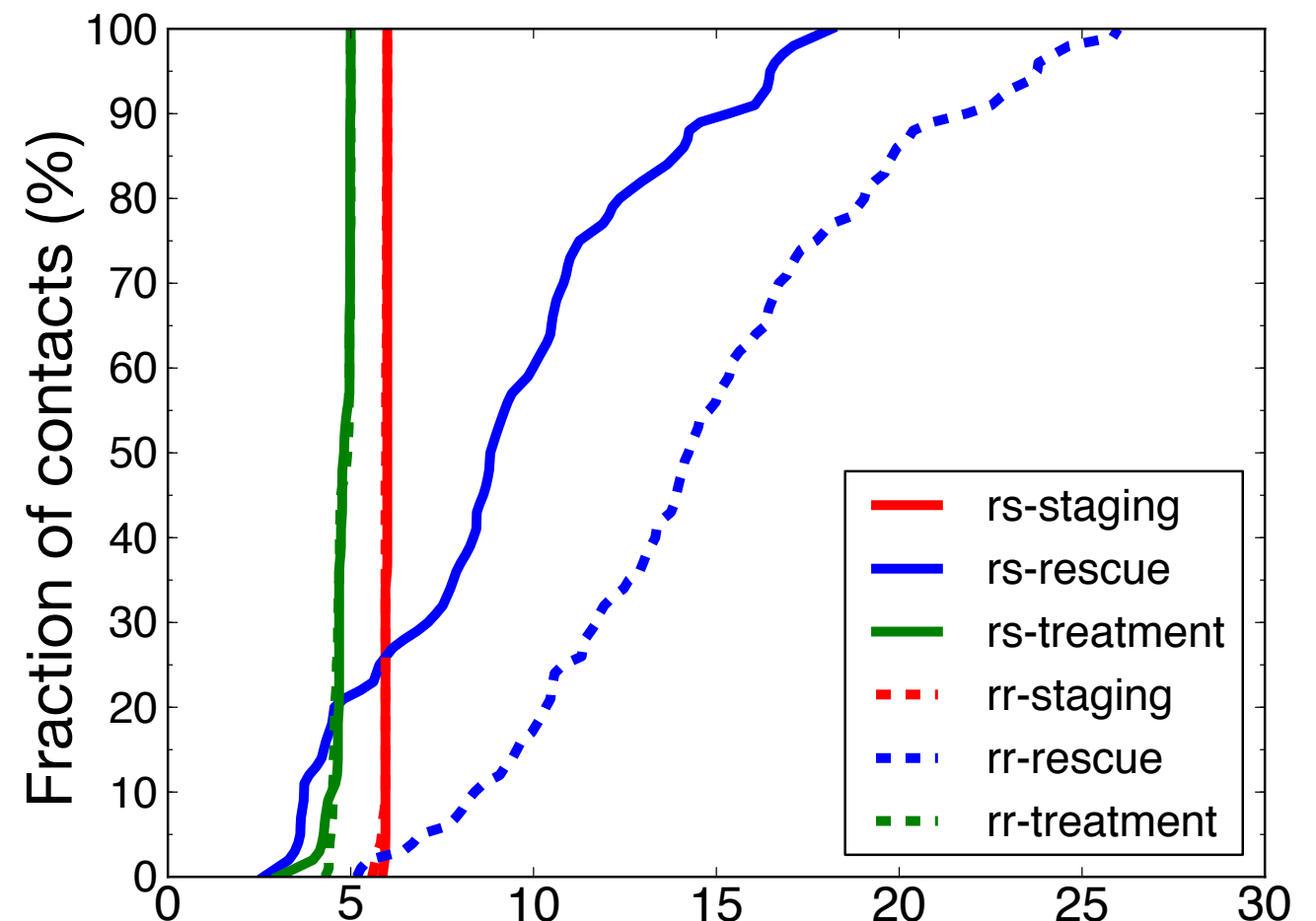
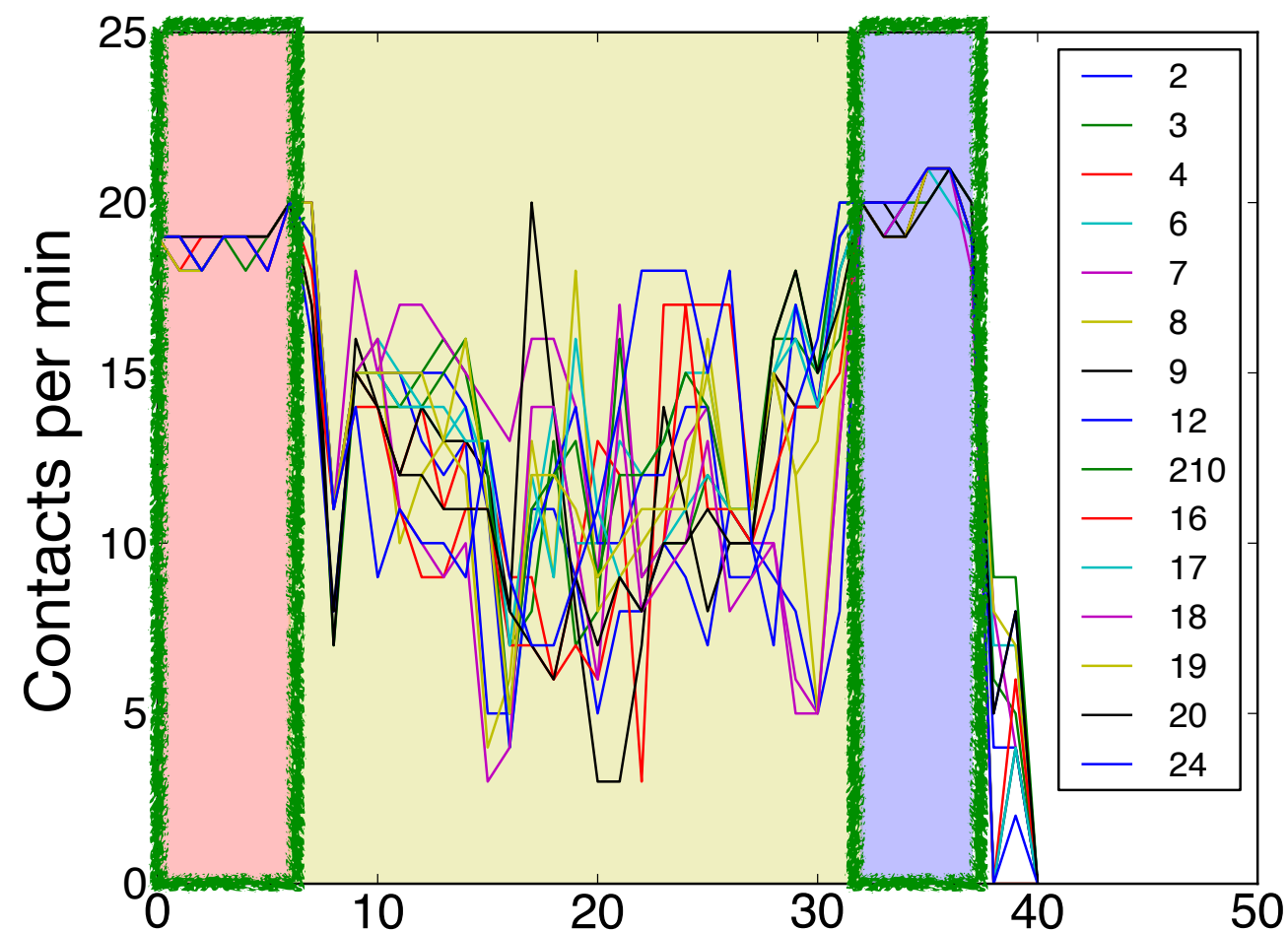
- **Understand the underlying network properties:**
 - What are the underlying network properties during the drill?
 - How do these properties vary with drill phases and responder roles?
 - What is the impact of mobility on network properties?
 - **Analysis approach: understand the impact of ICS on the network properties during the drill**
- **Evaluate the application reliability obtained via DTN techniques**

Link properties



- **Link properties vary with drill phases**
 - high variability in the number of contacts during rescue phase
- **Long-term link properties depend on the roles of responder in the drill**
 - staging & treatment: good connectivity between responders and supervisors
 - rescue: poor connectivity between responders and supervisors

Link properties



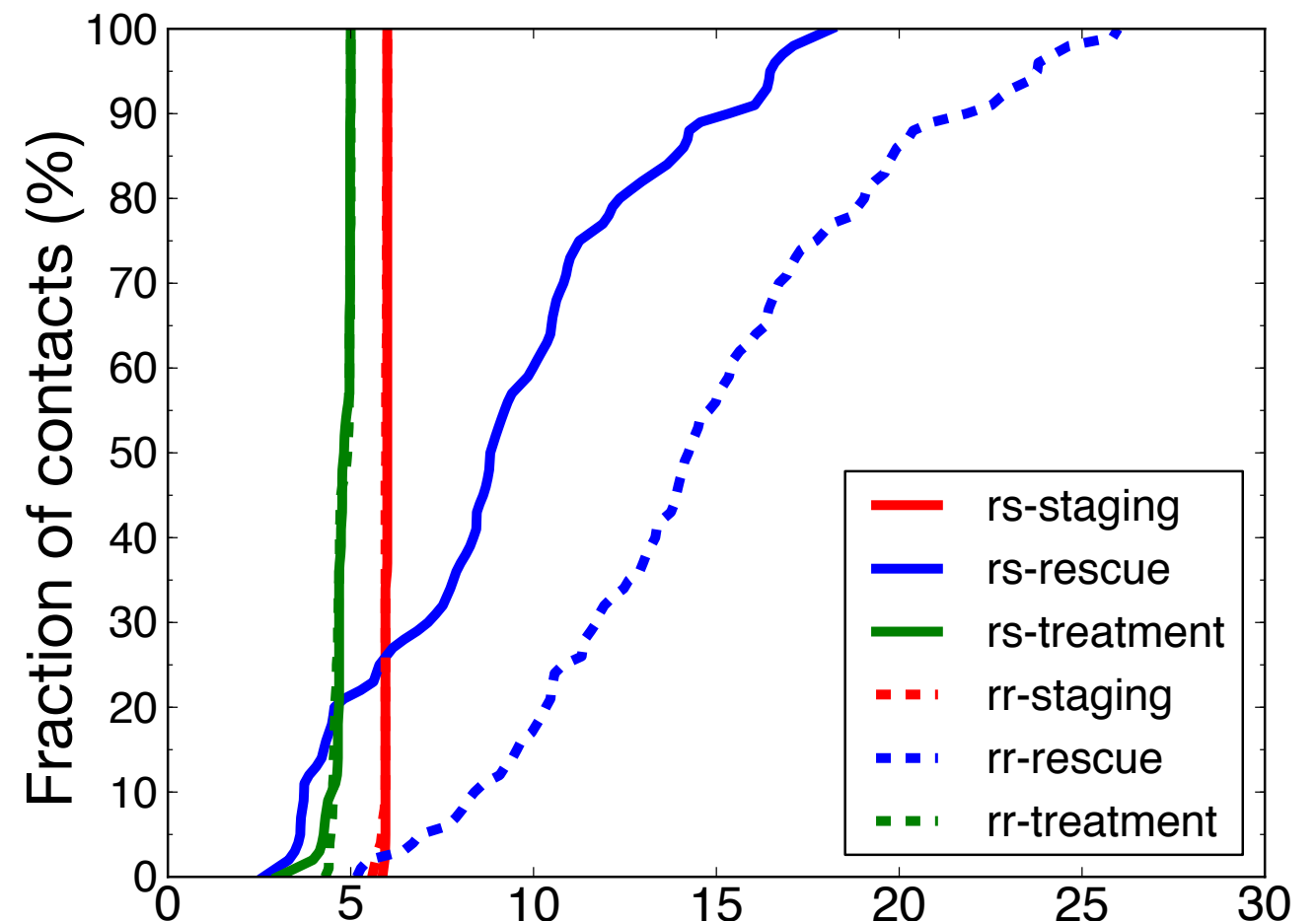
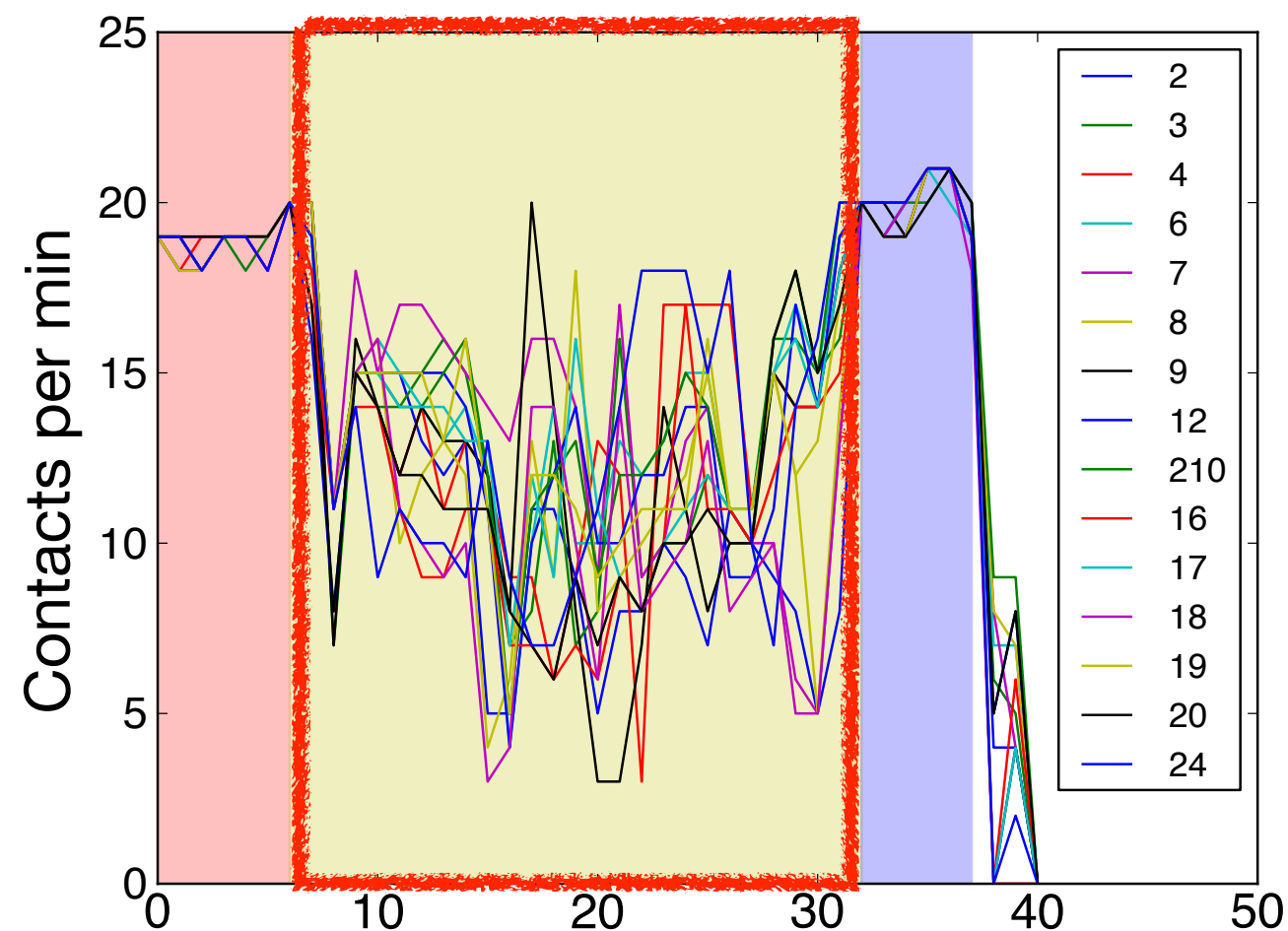
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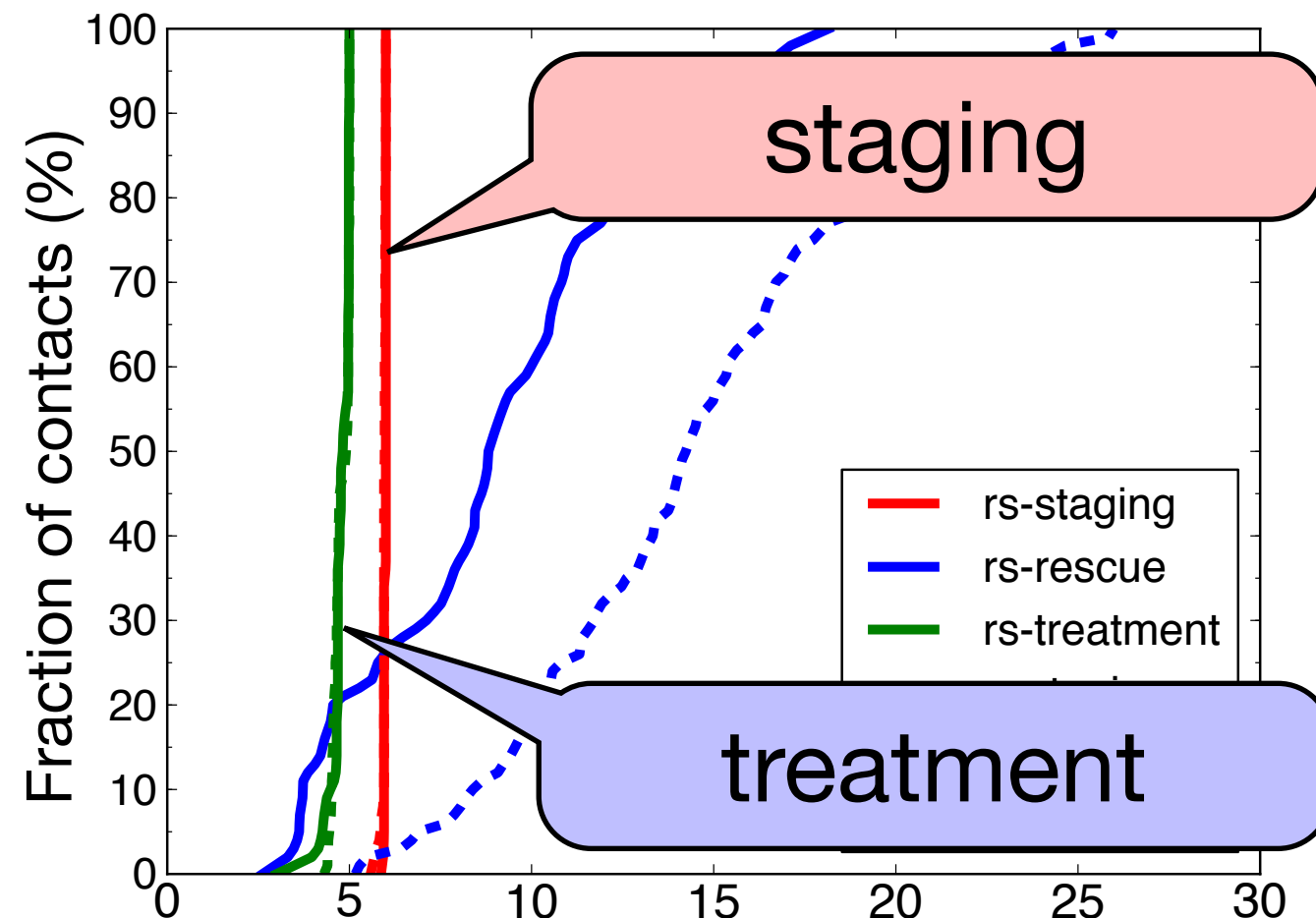
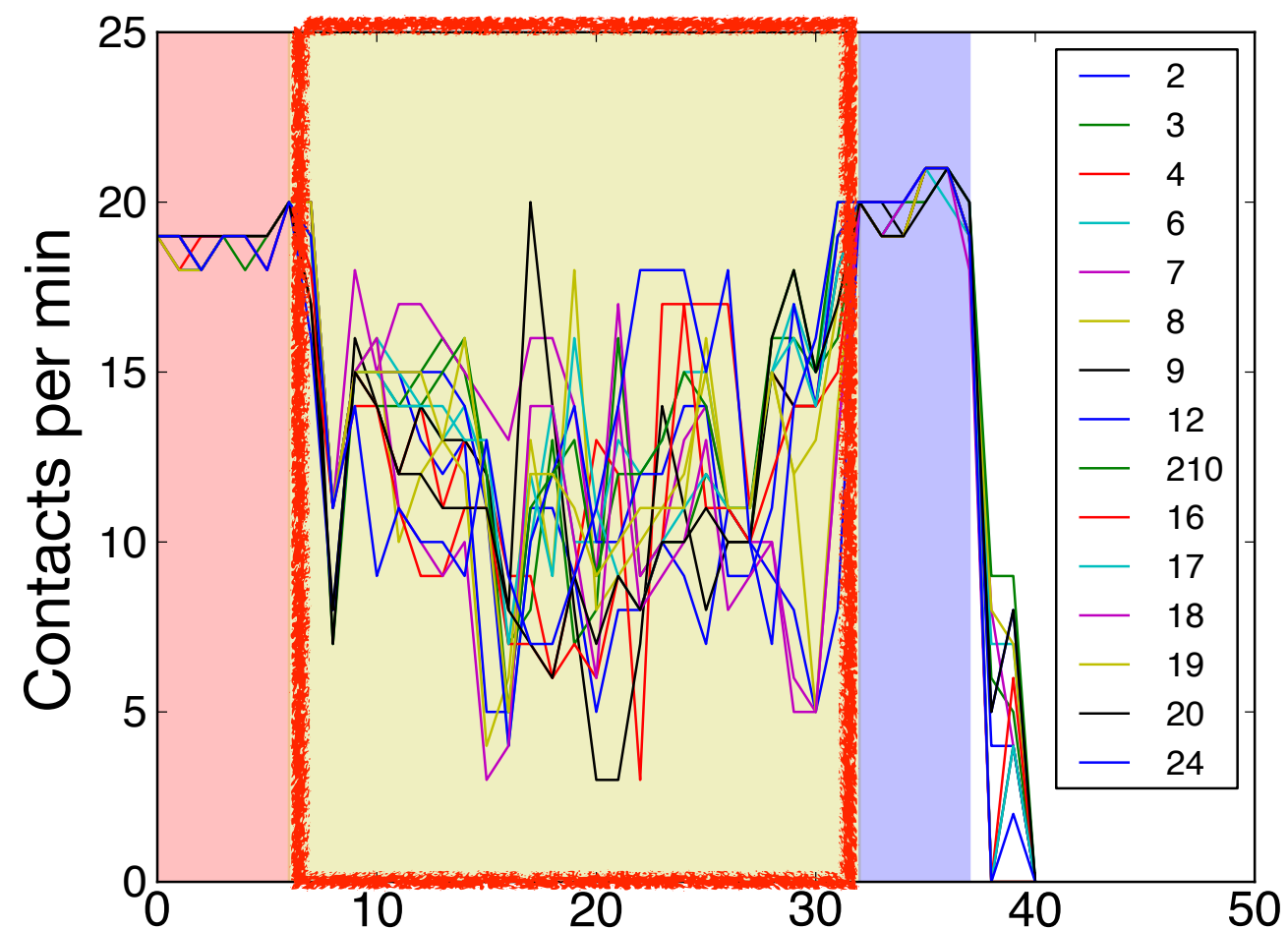
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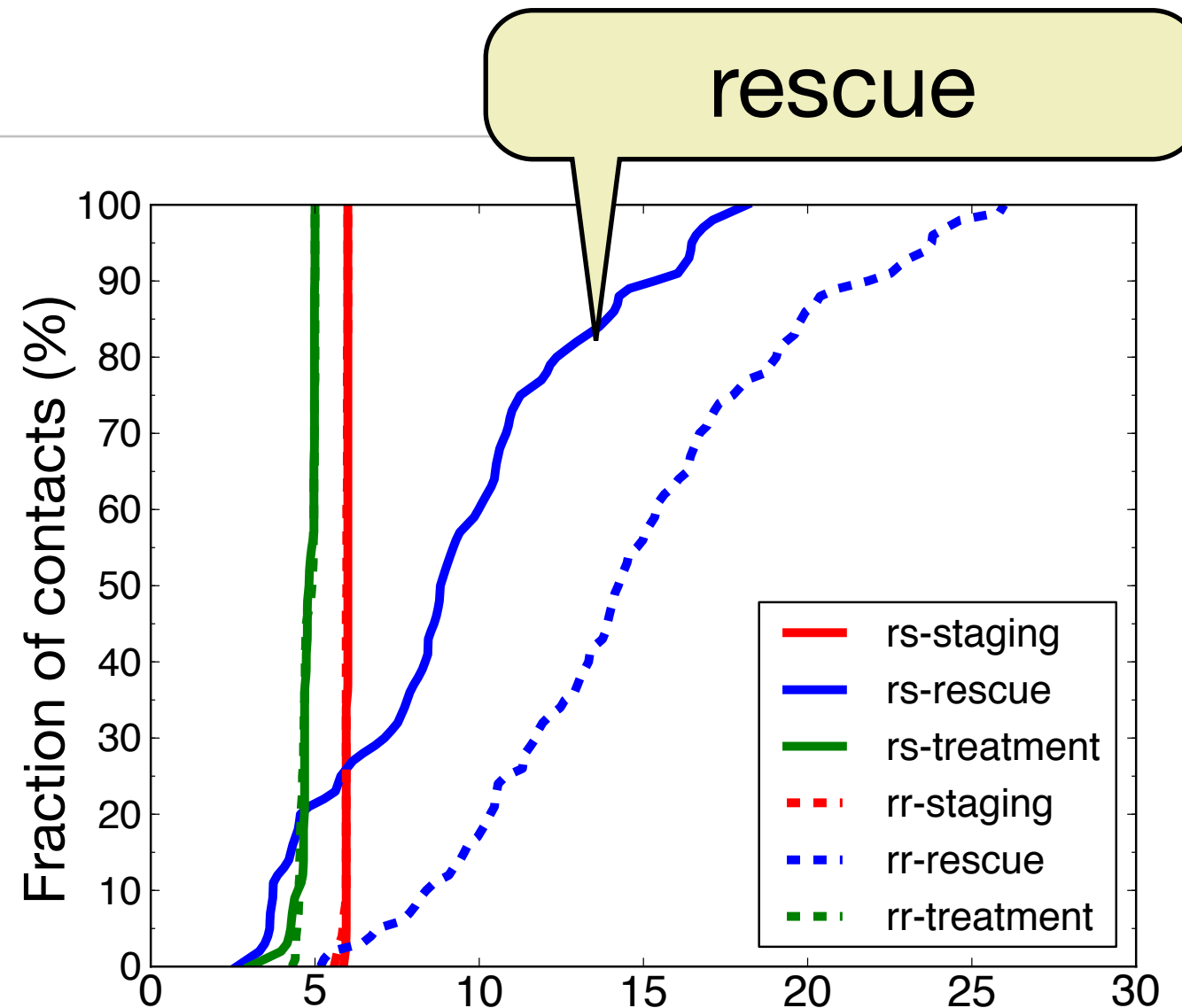
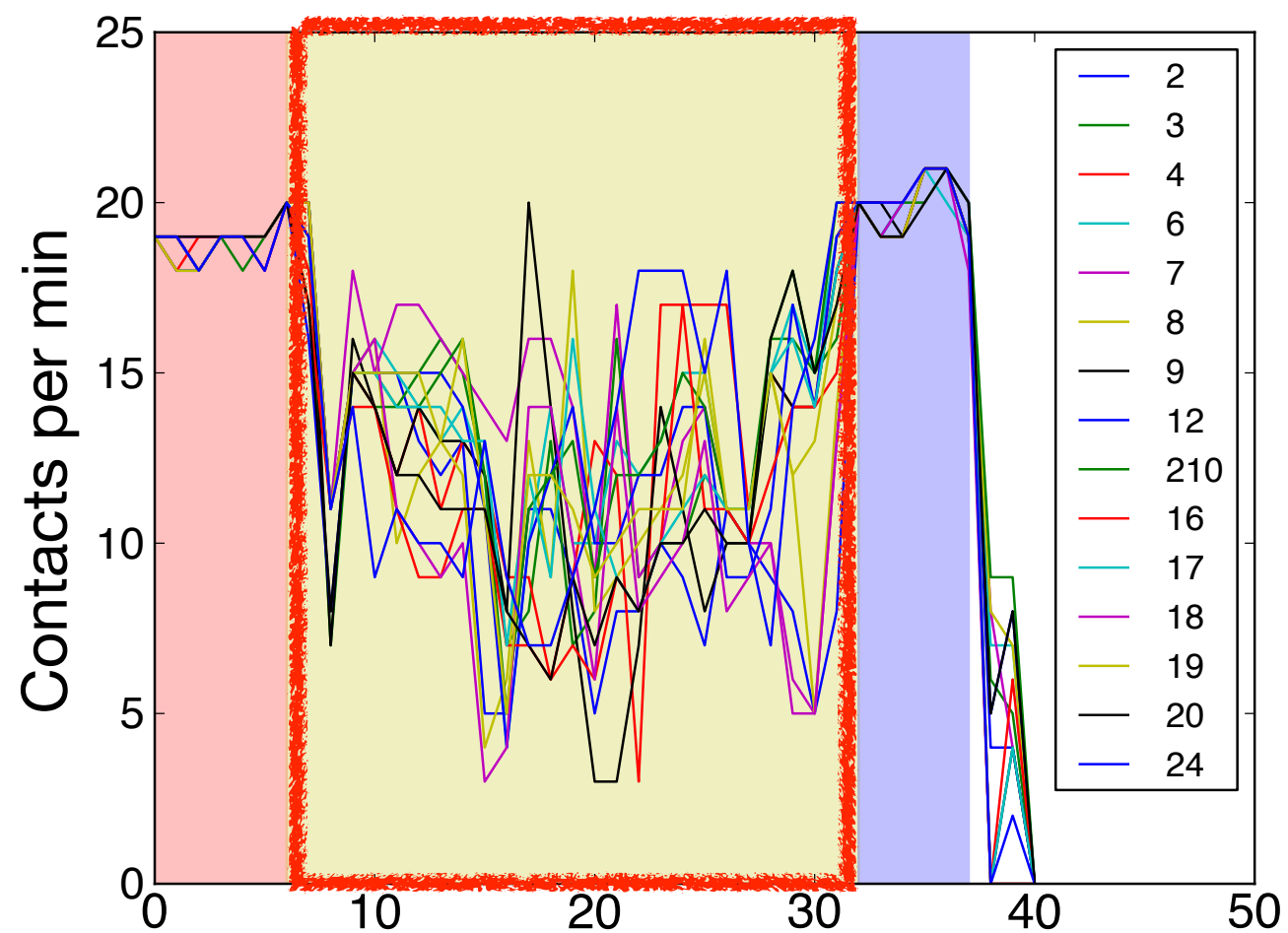
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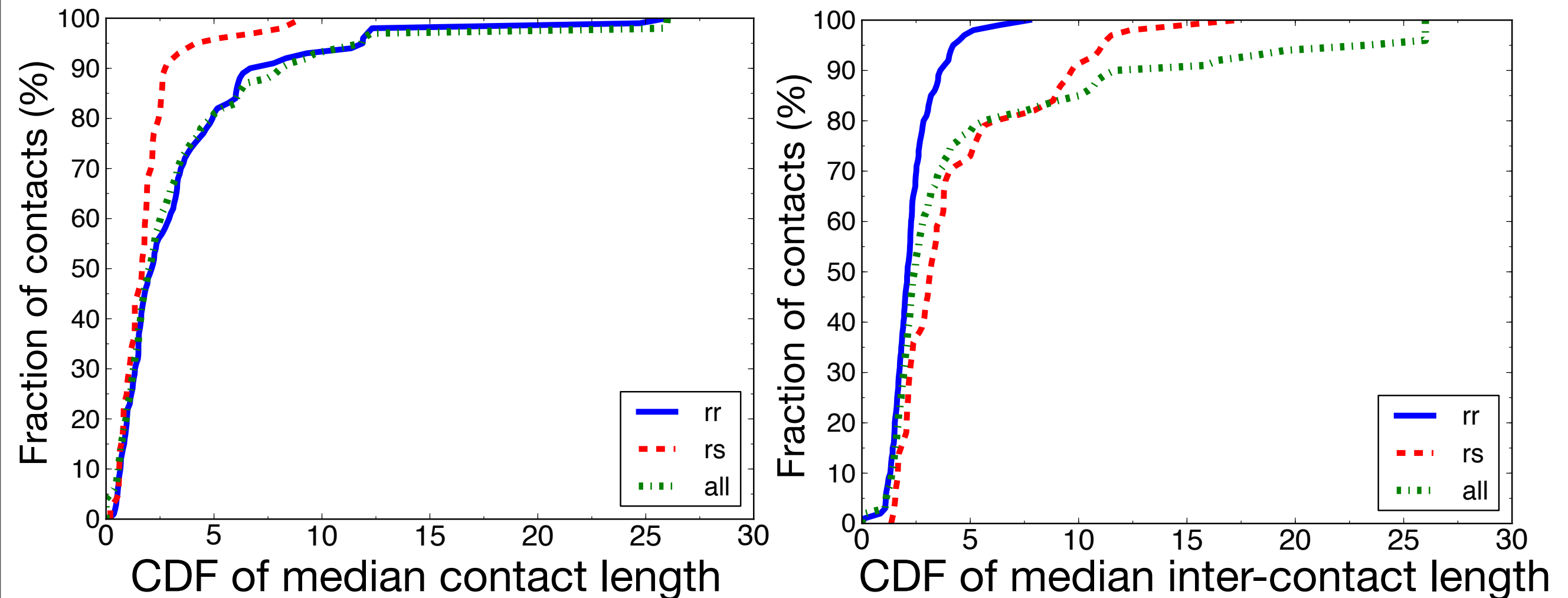
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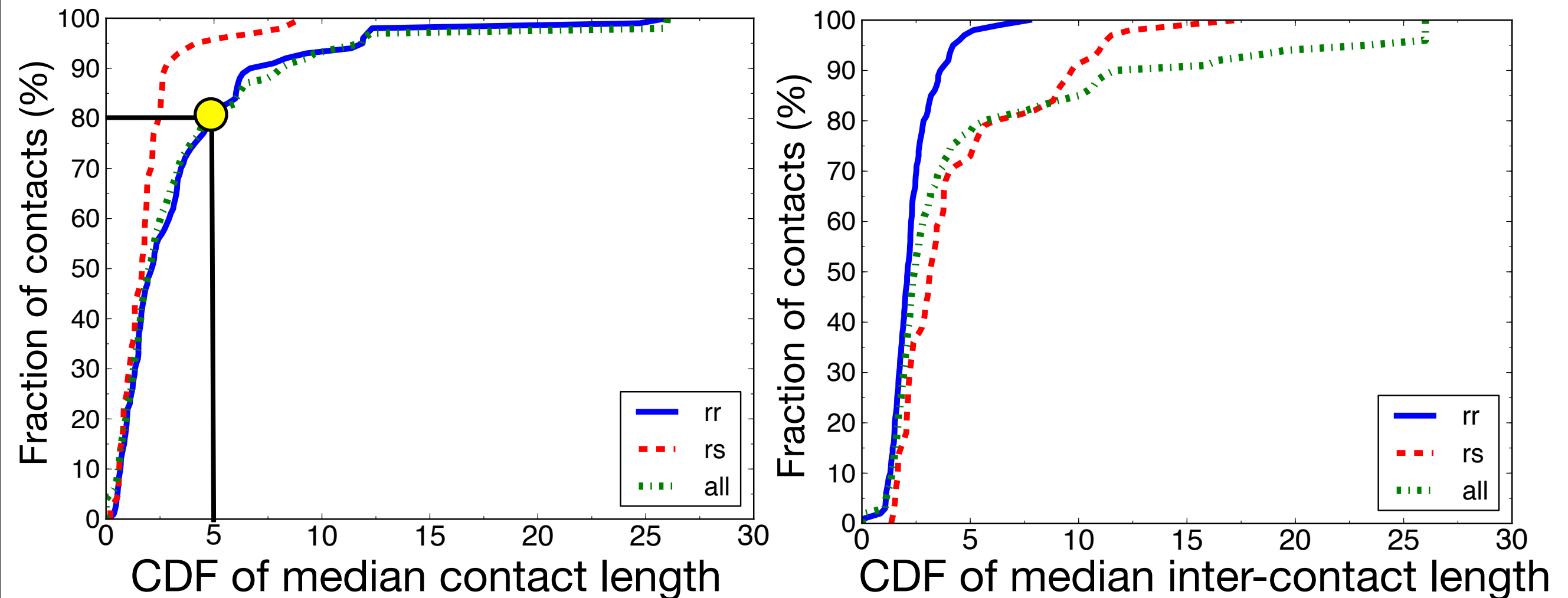
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Contacts between responders during rescue phase



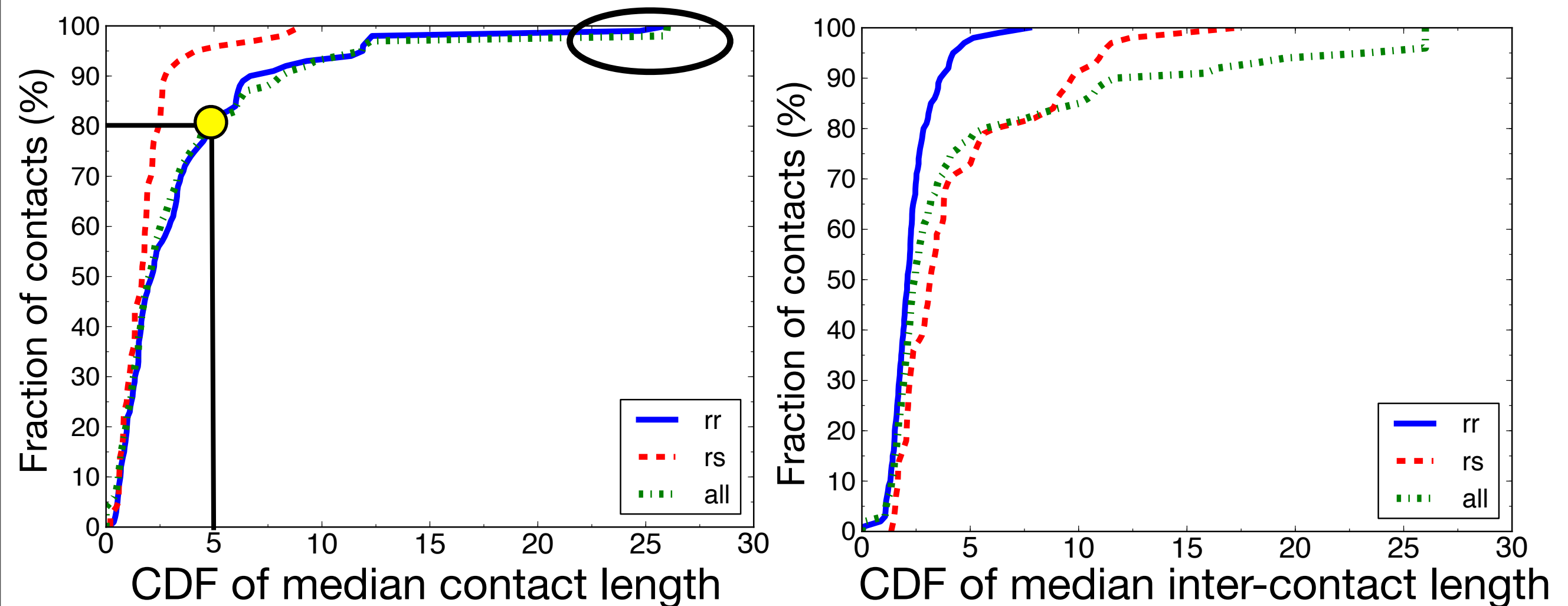
- **Contacts between responders are typically short**
 - 80% of contacts have a median contact length < 5 mins
 - long tail → working in teams leads to some prolonged stable contacts
- **Contacts are often reestablished within minutes**
- **Highly dynamic environment**

Contacts between responders during rescue phase



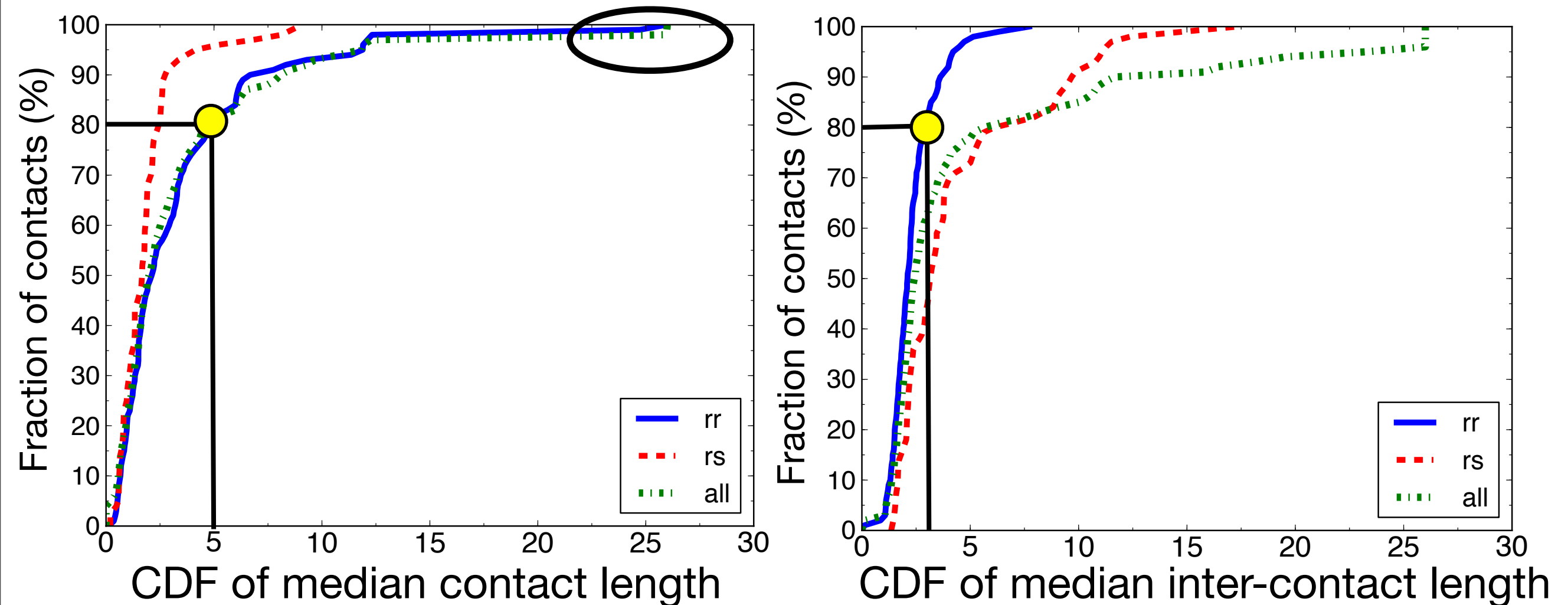
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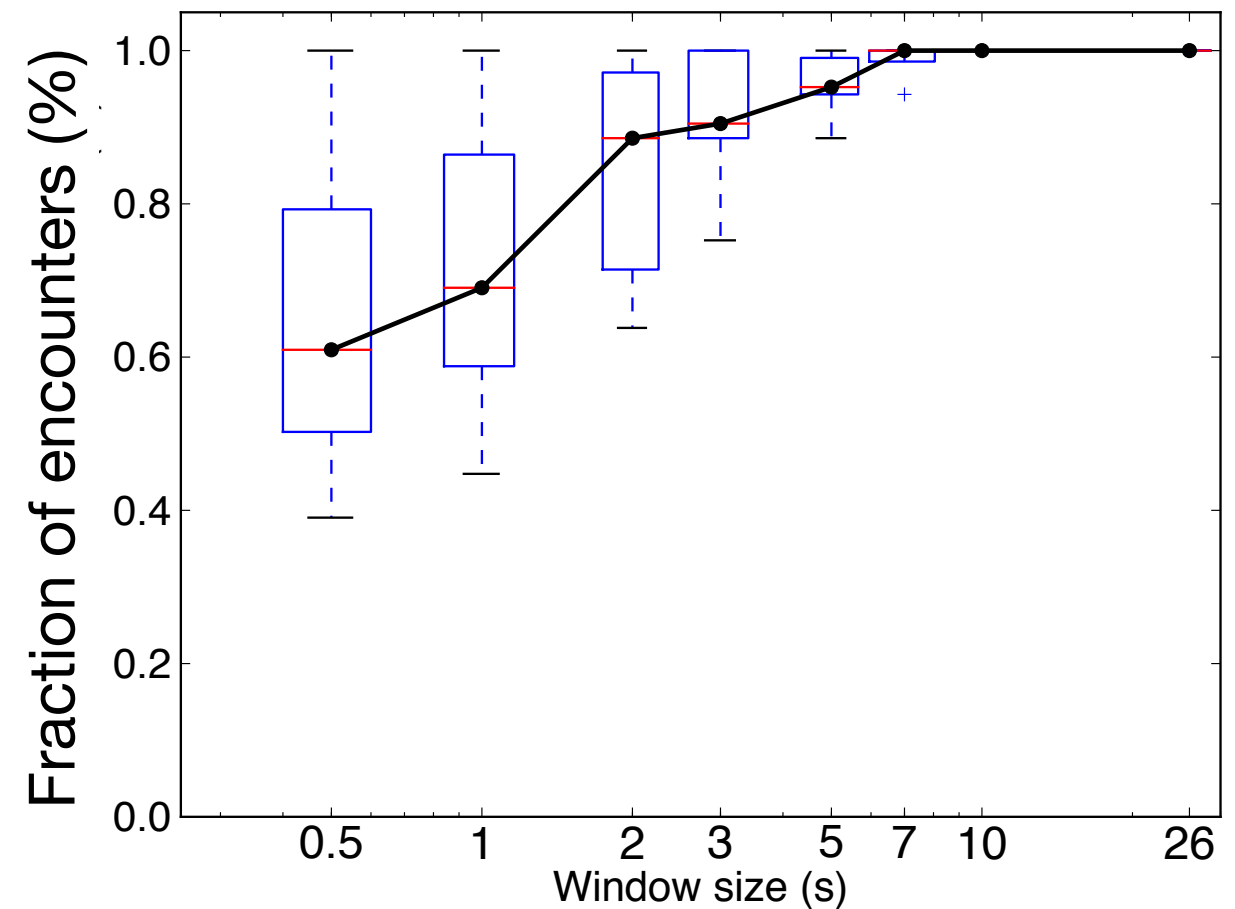
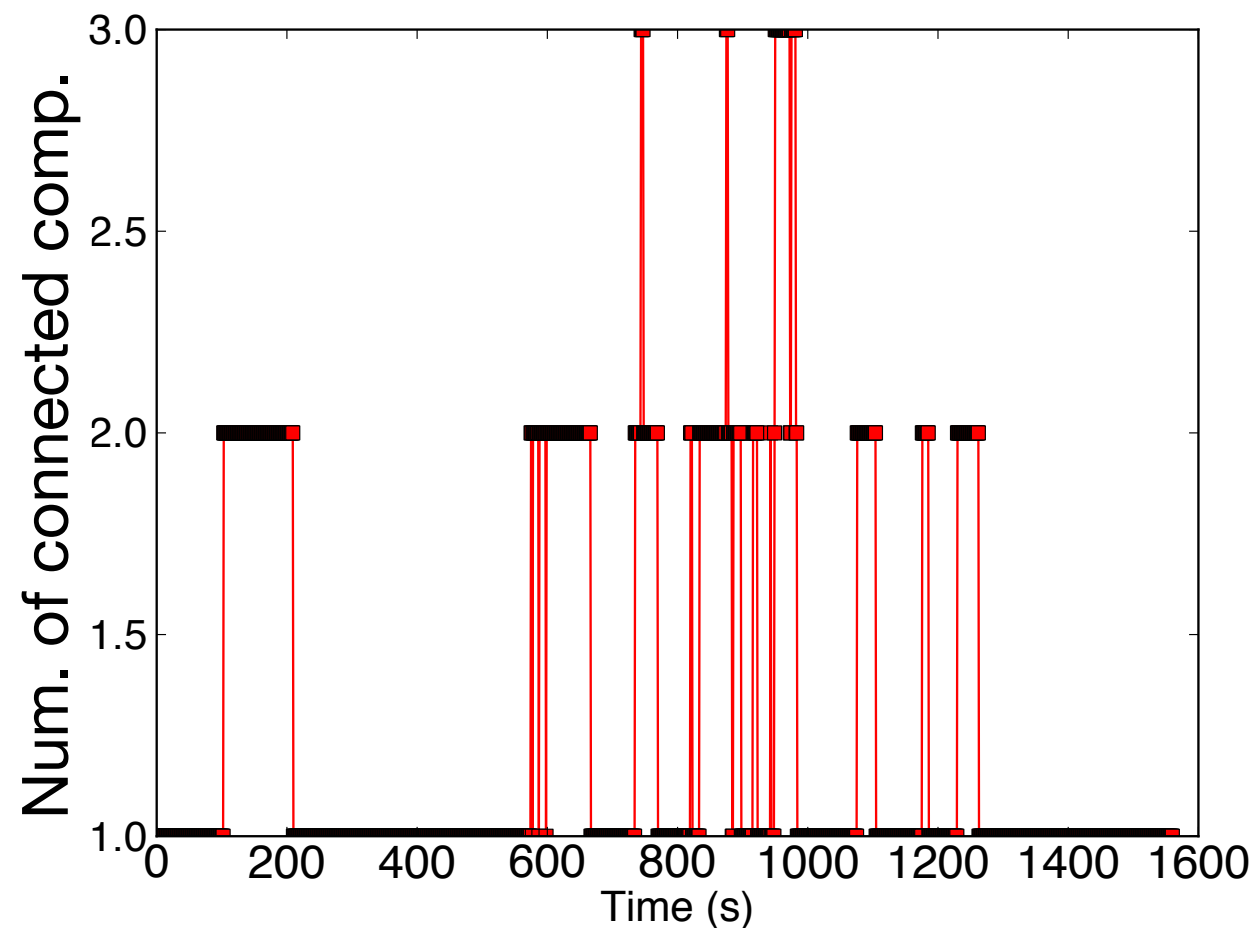
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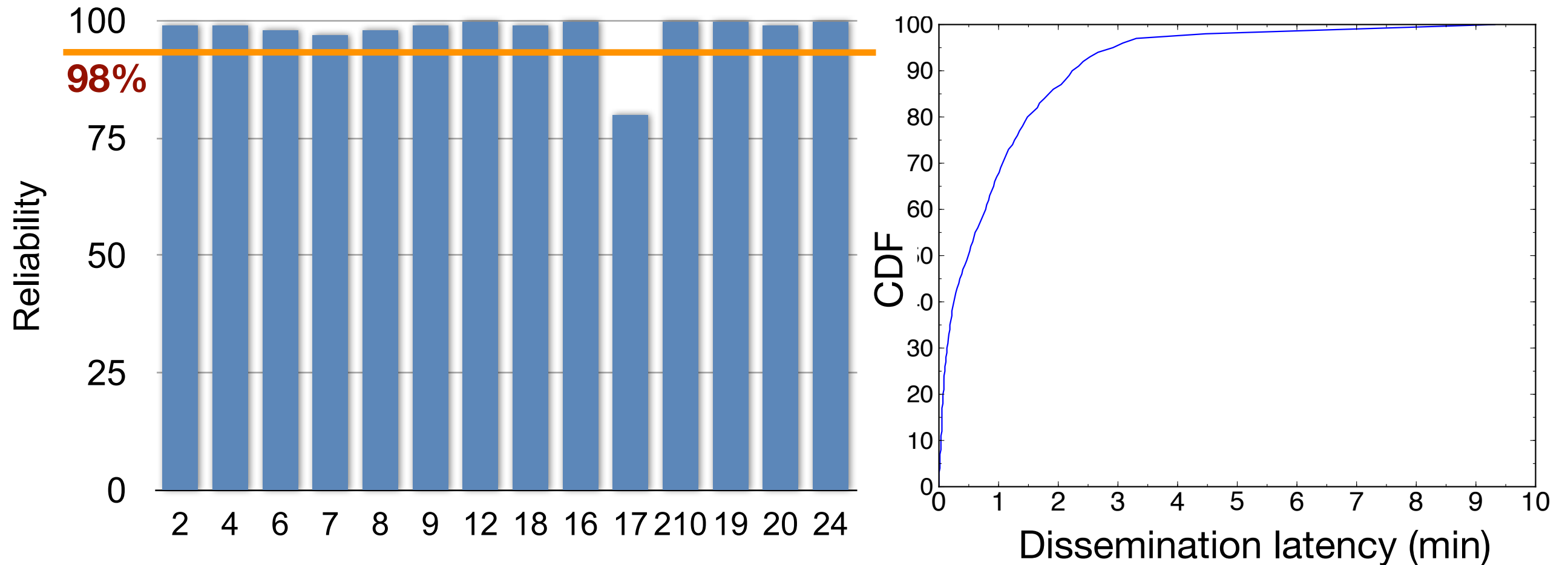
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Network partitions and impact of mobility



- **Partitions were common during rescue phase**
 - 26.3% of the rescue phase the network was partitions
- **Mobility helps disseminating data through data muling**
 - within 7 minutes a responder meets all other responders

Application performance



- **Reliability:**

- median reliability 98% per source

- **Delay:**

- 90% of data delivered with 5 minutes, max delay 10 minutes

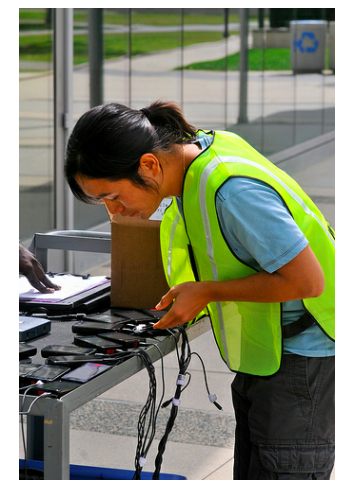
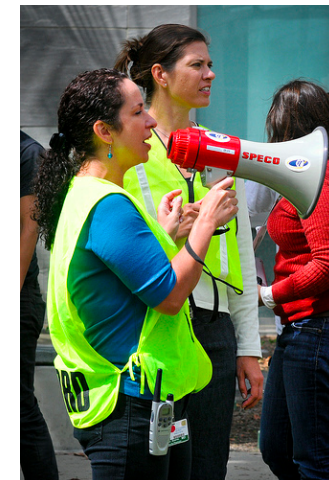
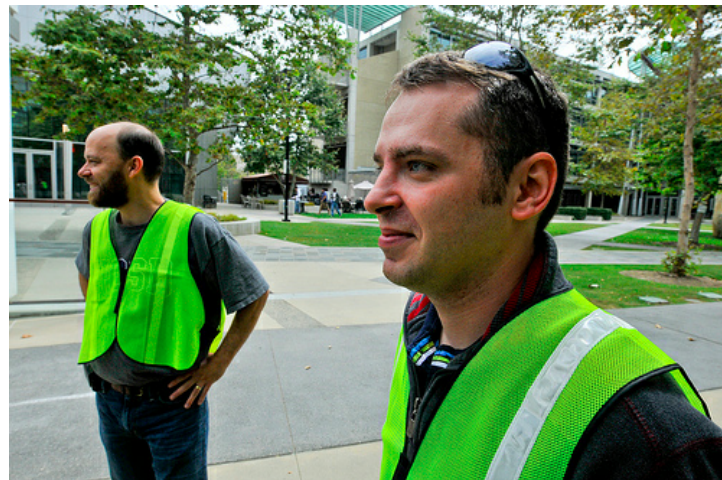
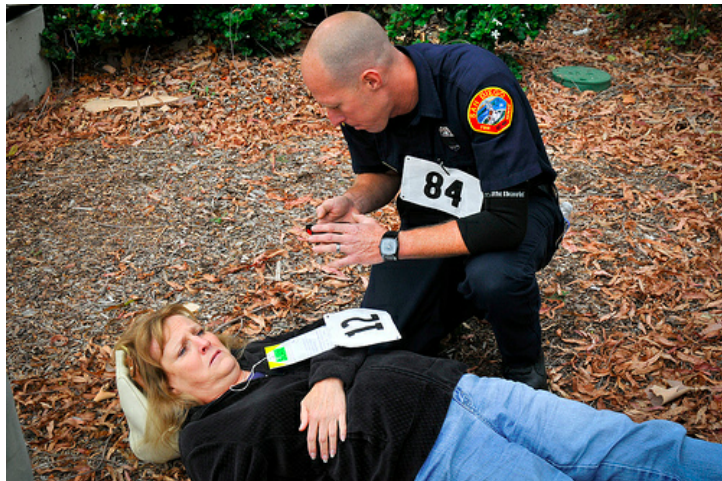
- **Shows the feasibility of DTN-based techniques**

Conclusions and future work

- **One of the first empirical studies of network properties during a drill**
 - **Incident Command Structure → network properties**
 - link properties vary with the phase of the drills
 - link properties vary with the role of the responders during the drill
 - network partitions are common
 - mobility significantly improves dissemination of data
 - **validation from multiple drills required**
- **WIISARD - a reliable emergency response system**
 - 98% median reliability, 95% of data disseminate within 2.5 minutes
 - shows the feasibility of DTN techniques in emergency response systems
- **On-going: simulator for evaluating emergency response systems**
 - use the Incident Command Structure as a generative model

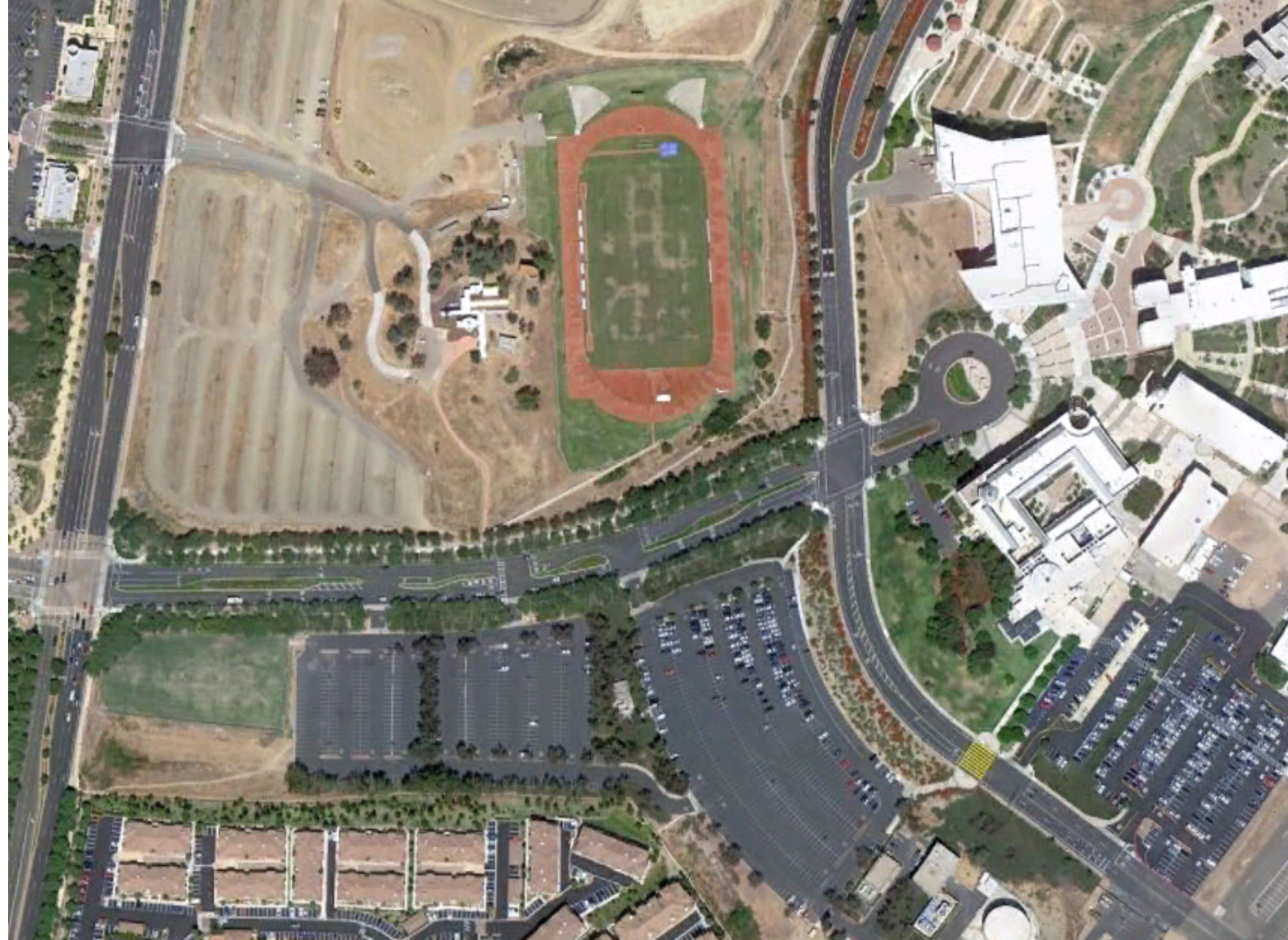
Acknowledgements

- **First responders and participants in the UCSD drill exercise**
 - without them, we would not be here
- **Other members of the WISARD team that helped plan the drill**
- **Our funding agencies: NIH and NSF**



Questions?

Incident command structure (ICS)



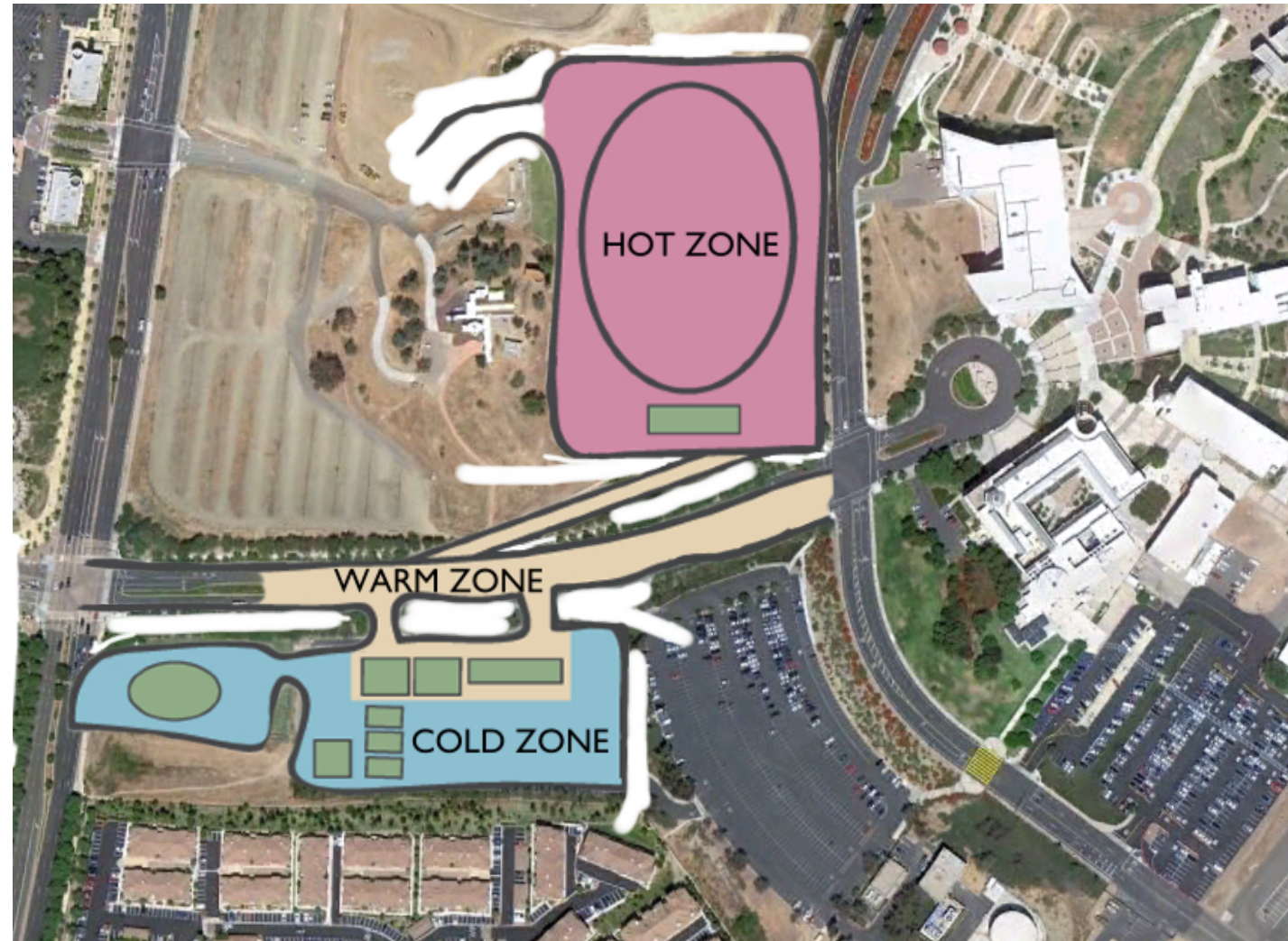
staging

rescue

treatment

transport

Incident command structure (ICS)



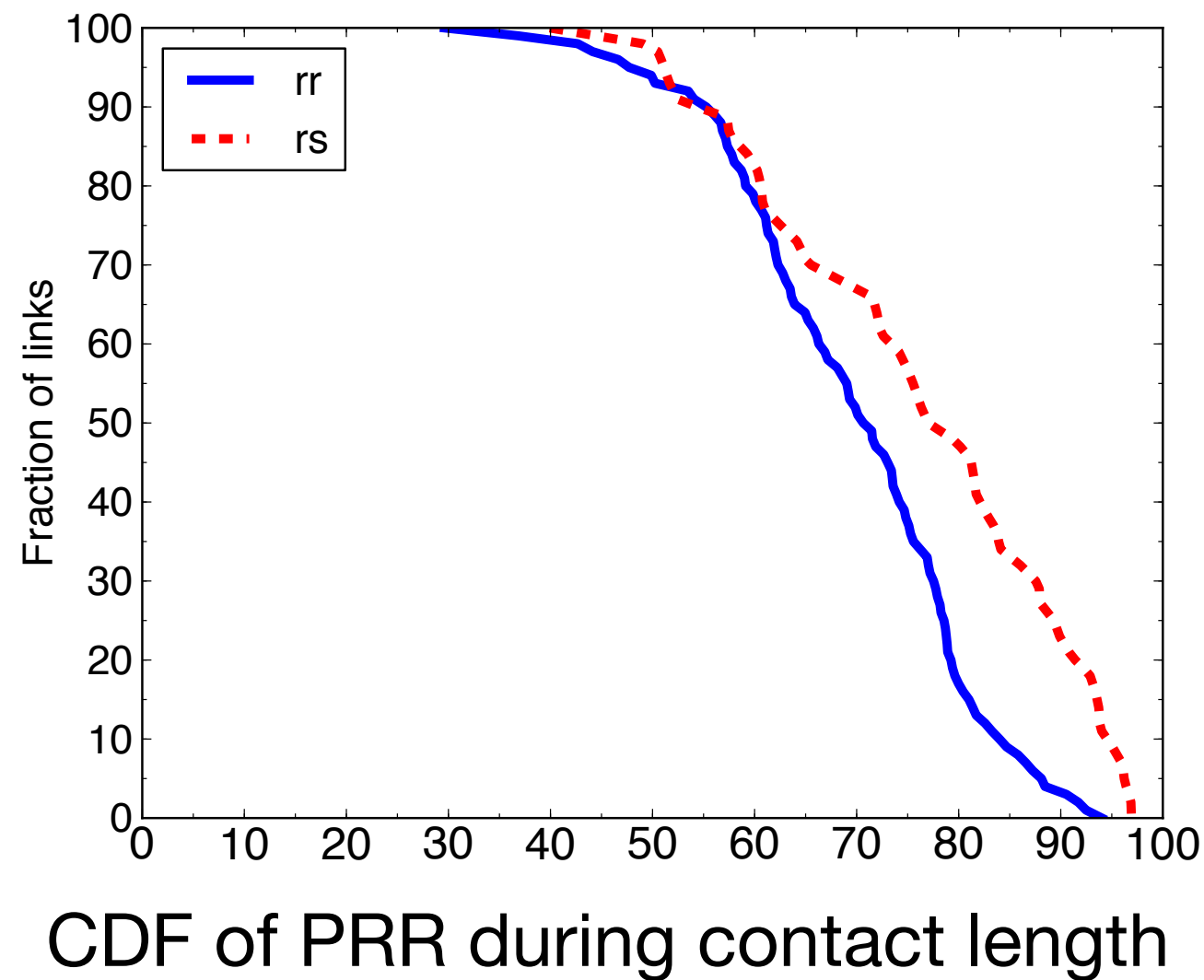
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Link quality during contacts



- The short-term link quality while contacts are established is high.