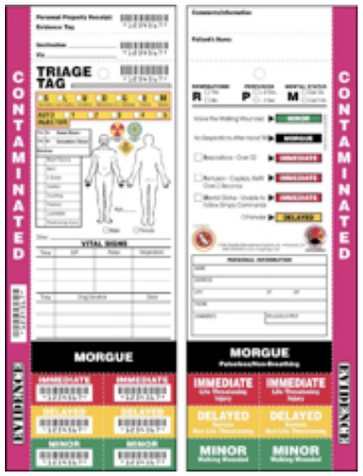
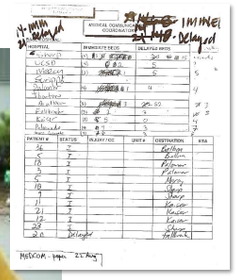
A Measurement Study of Network Properties and Protocol Reliability during an Emergency Response

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

Motivation

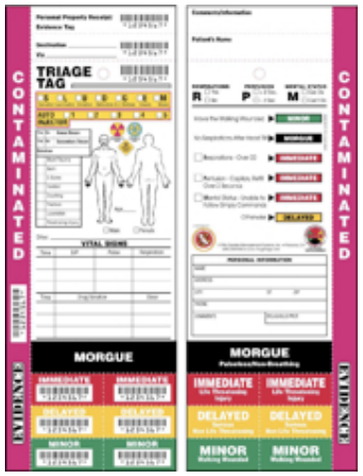


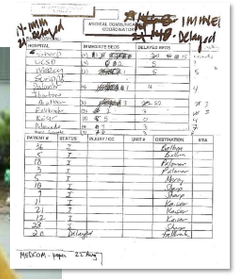


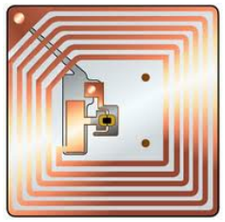
State-of-practice

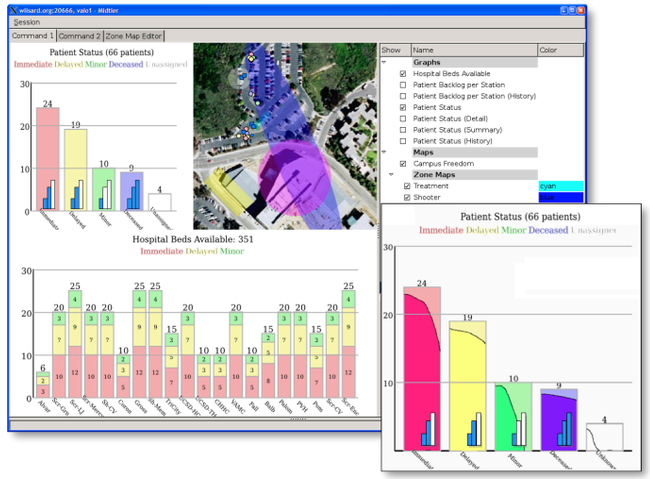
WIISARD

Motivation





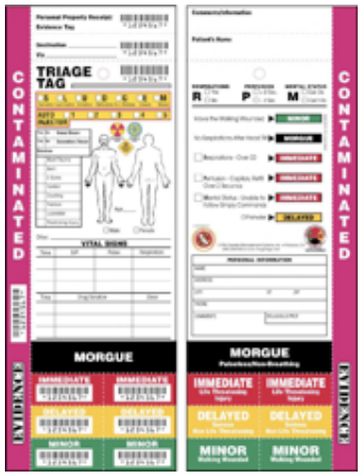


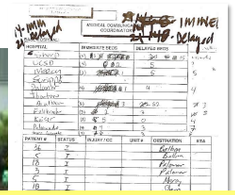


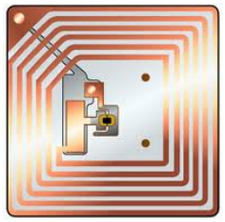
State-of-practice

WIISARD

Motivation

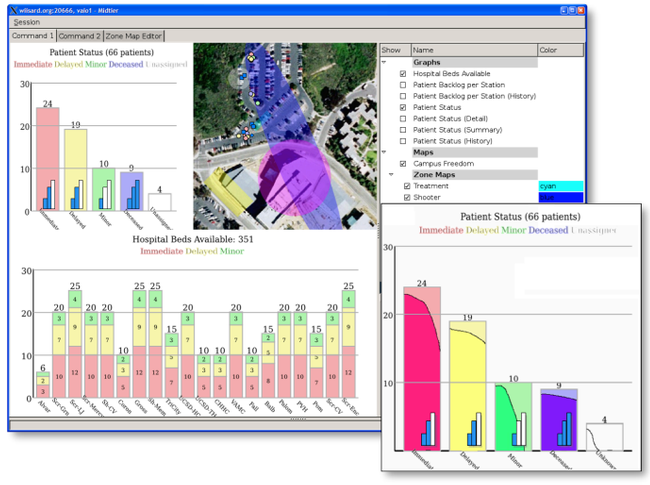






Fundamental Challenge:

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 - considerings a cooperative workflow

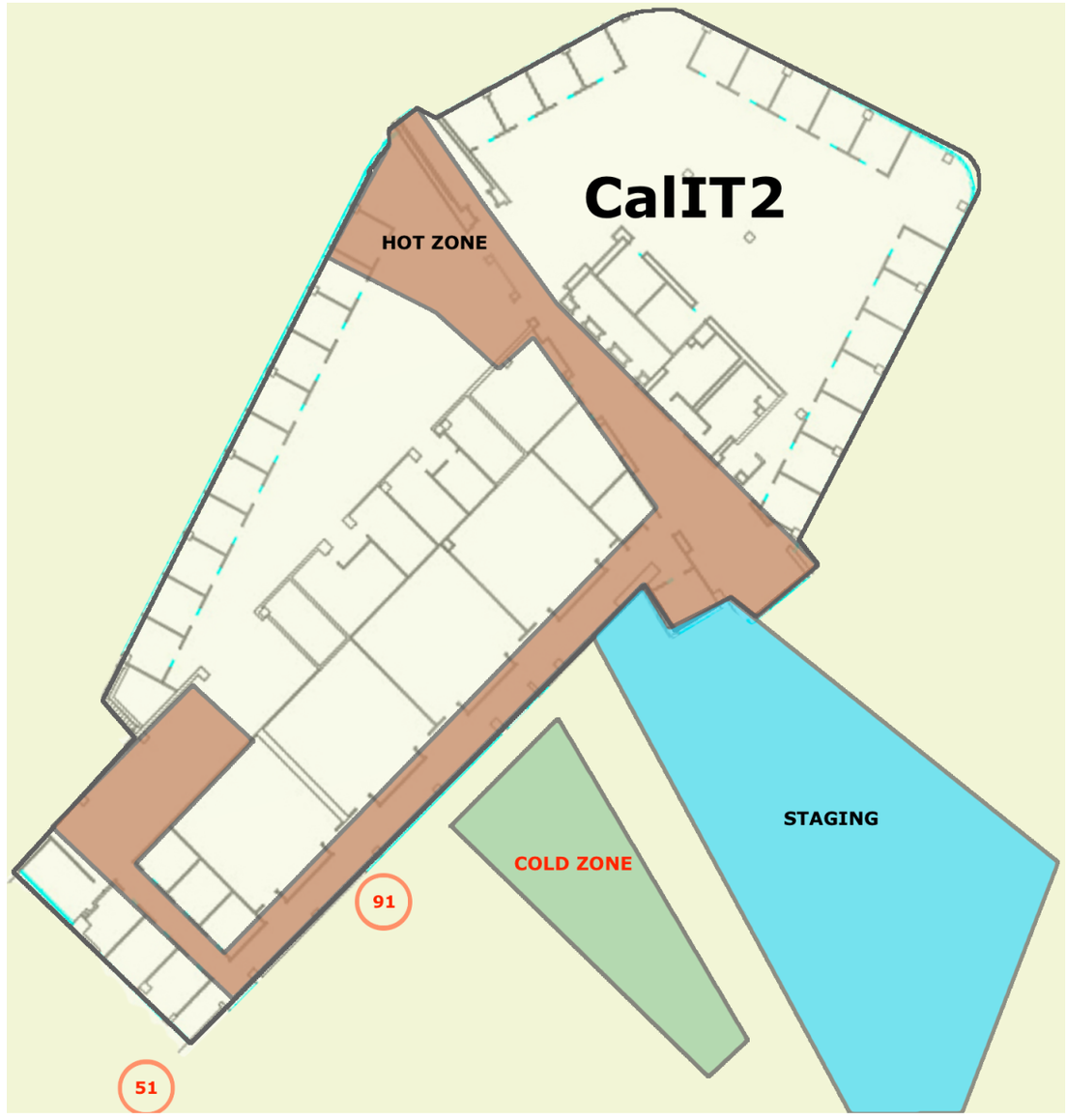
A reliable network architecture

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

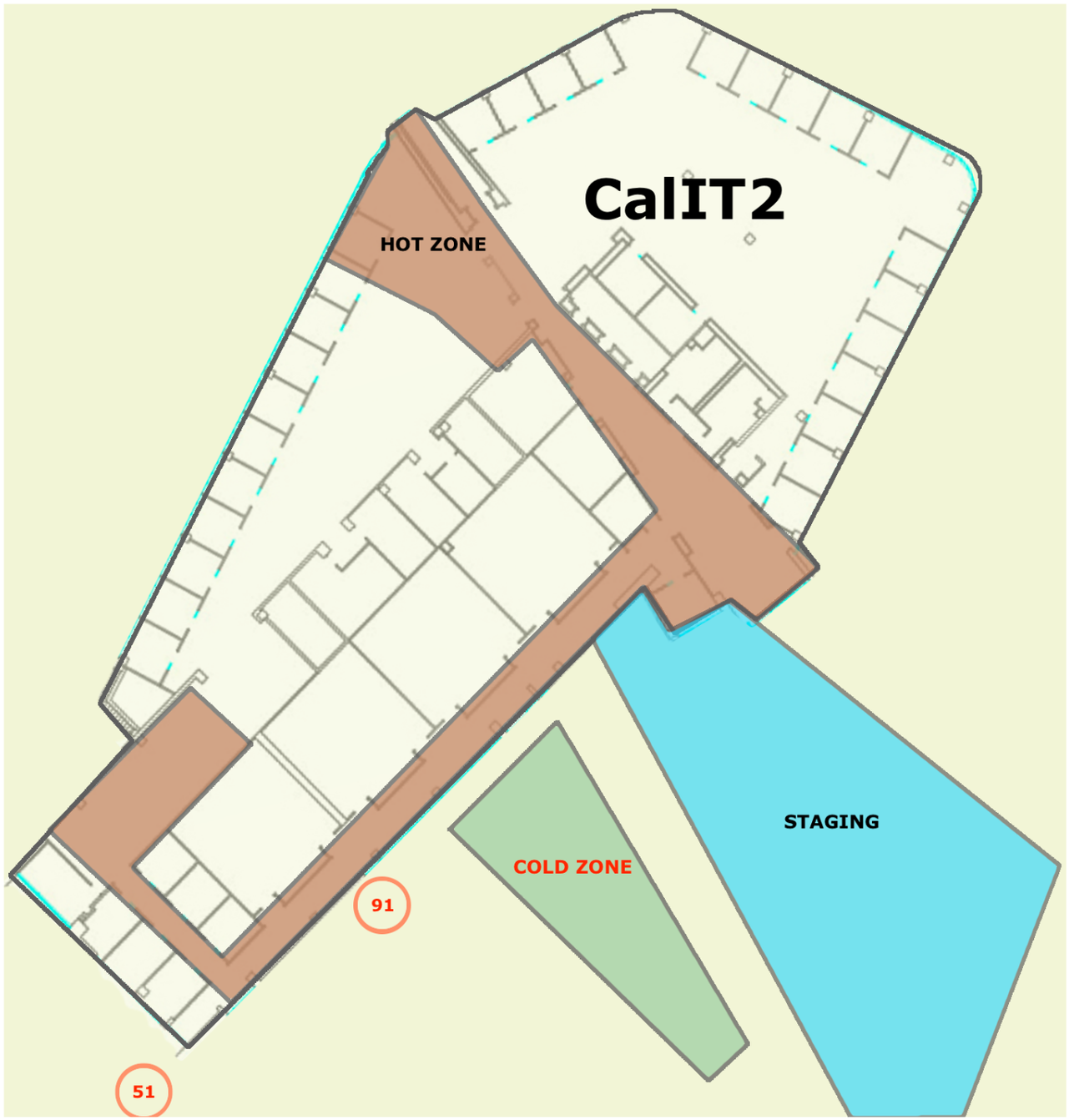
- **Approach:**
  - **communication primitive** - simple dissemination to all responders
  - **aggressive caching** - sufficient space to store all patient records on all devices
  - **gossip based protocol**
    - missing records identified through beacons
    - overhead reduced through suppressing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



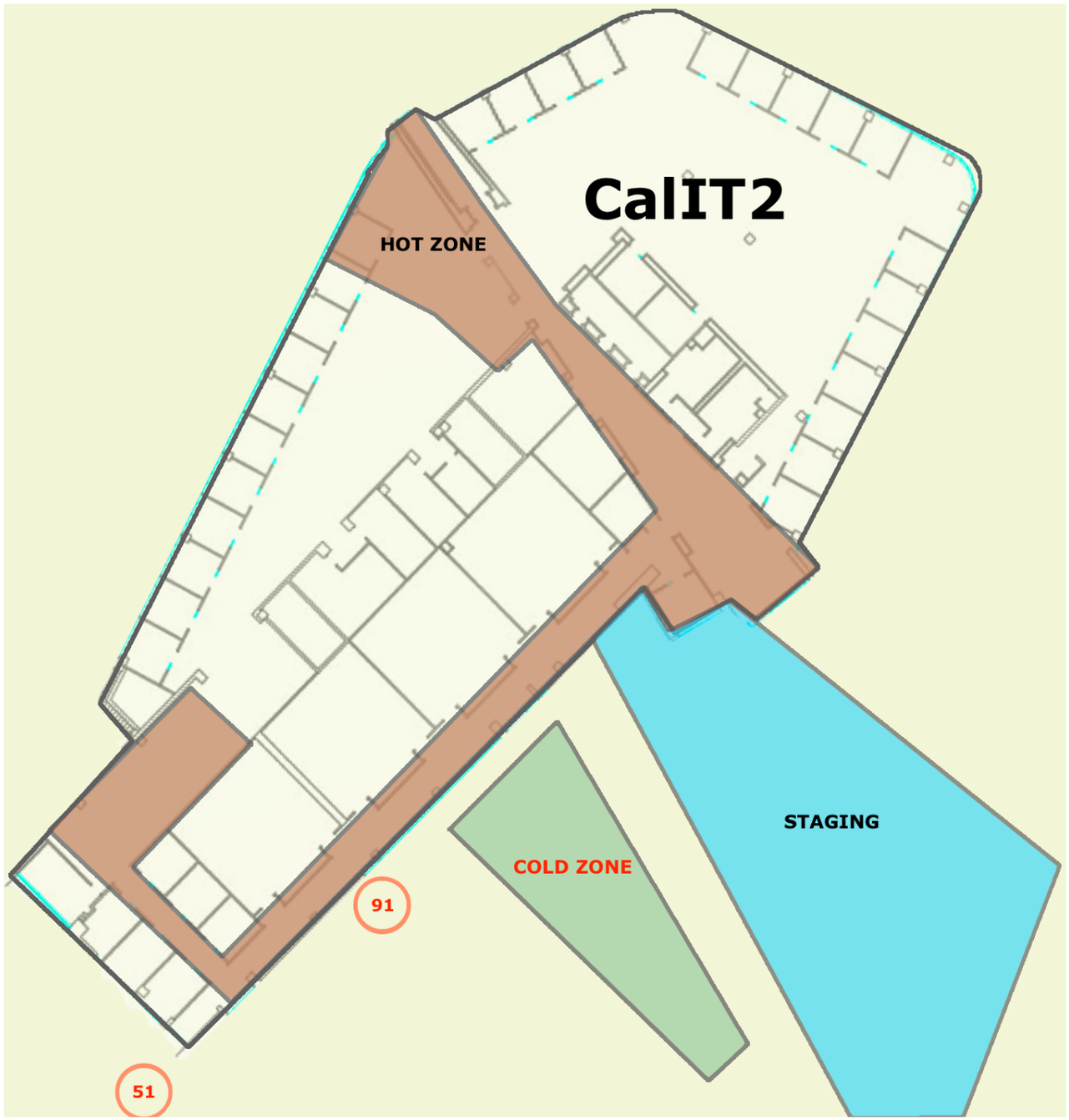
Incident Command Structure (ICS)



Scenario:

Major earthquake ⇒ 41 victims

Incident Command Structure (ICS)



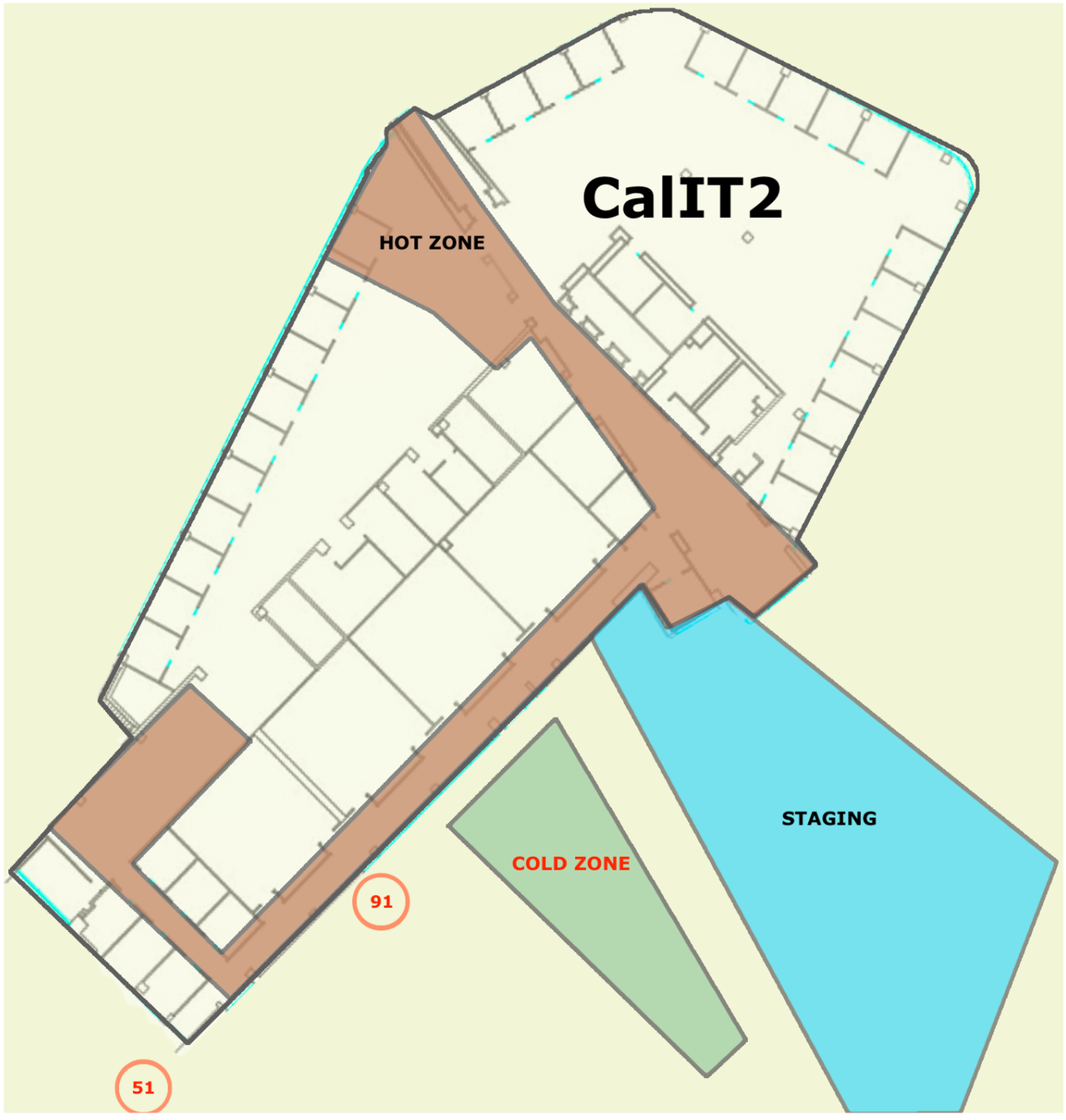
Scenario:

Major earthquake ⇒ 41 victims

Staging:

- responders arrive on scene

Incident Command Structure (ICS)



Scenario:

Major earthquake ⇒ 41 victims

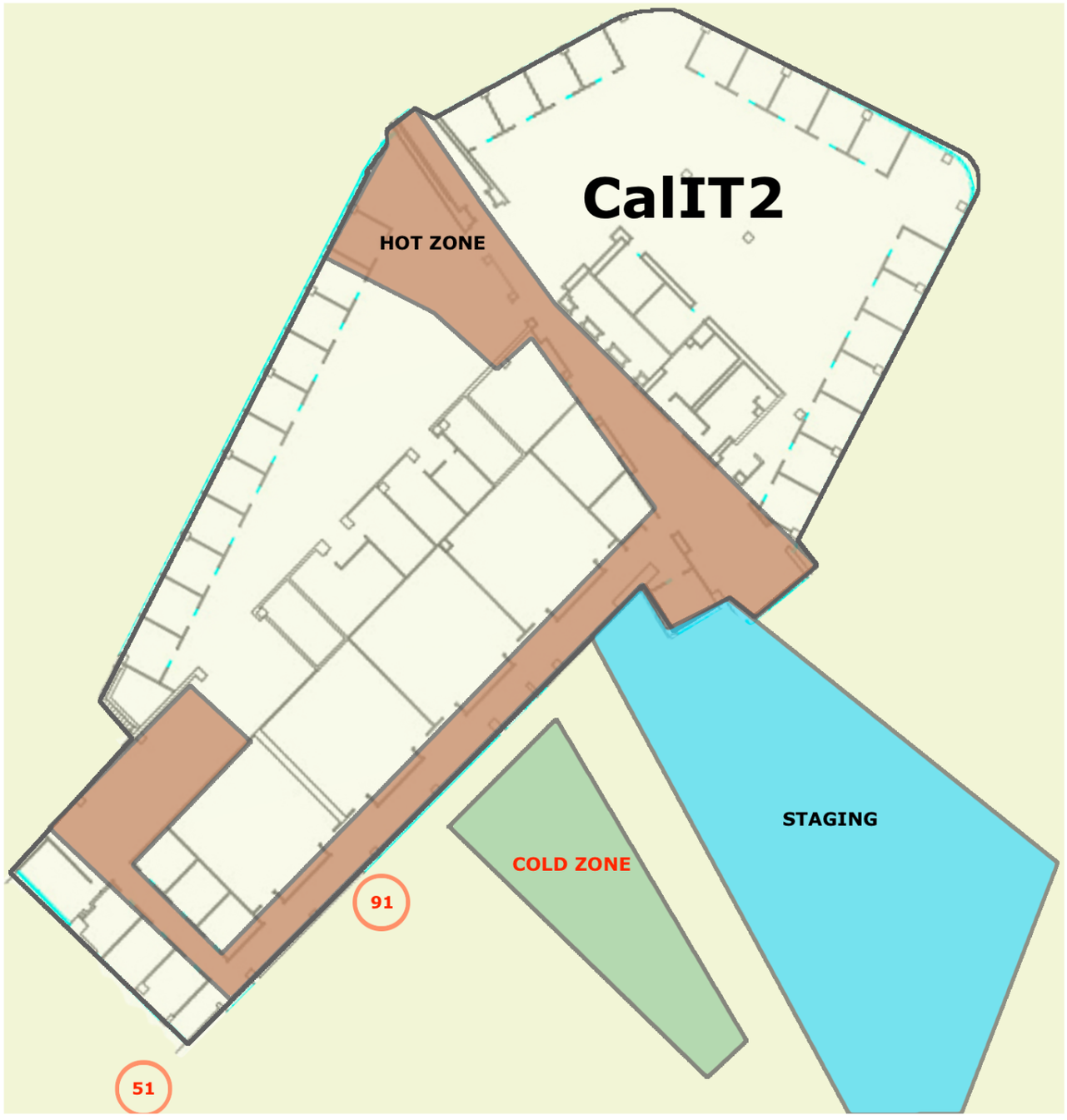
Staging:

- responders arrive on scene

Rescue:

- triage
- provide care
- evacuate

Incident Command Structure (ICS)



Scenario:

Major earthquake ⇒ 41 victims

Staging:

- responders arrive on scene

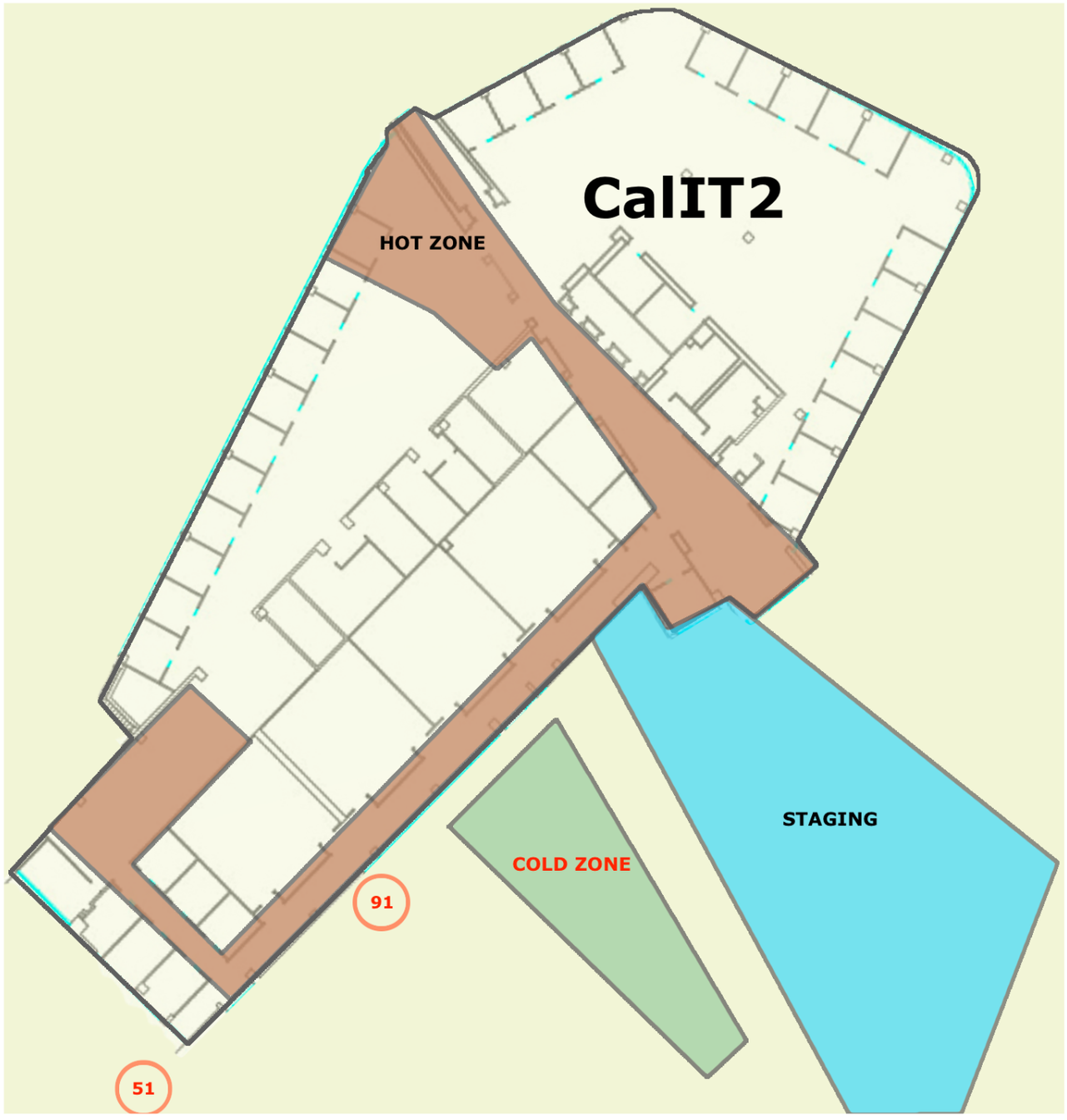
Rescue:

- triage
- provide care
- evacuate

Treatment:

- re-triage
- provide additional care

Incident Command Structure (ICS)



Scenario:

Major earthquake ⇒ 41 victims

Staging:

- responders arrive on scene

Rescue:

- triage
- provide care
- evacuate

Treatment:

- re-triage
- provide additional care

Transport:

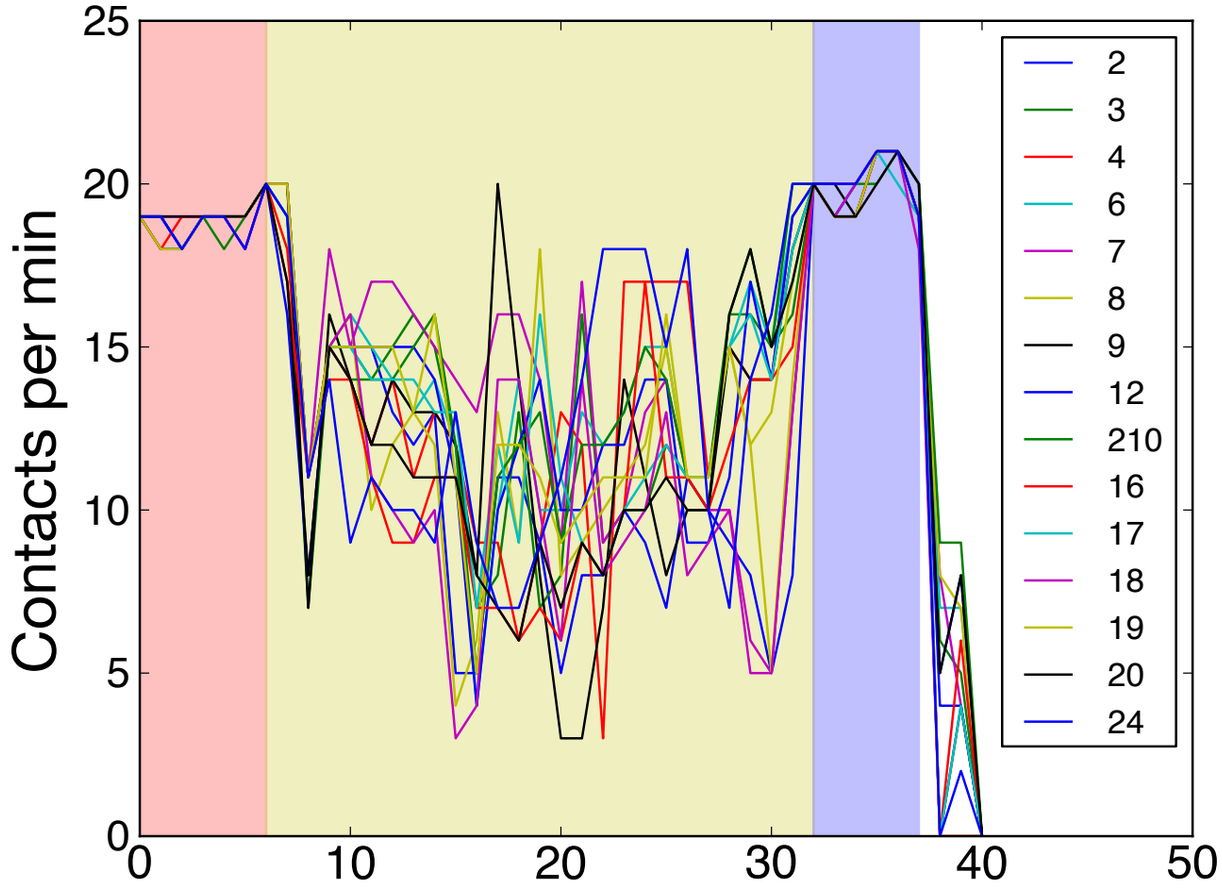
- transport to hospitals

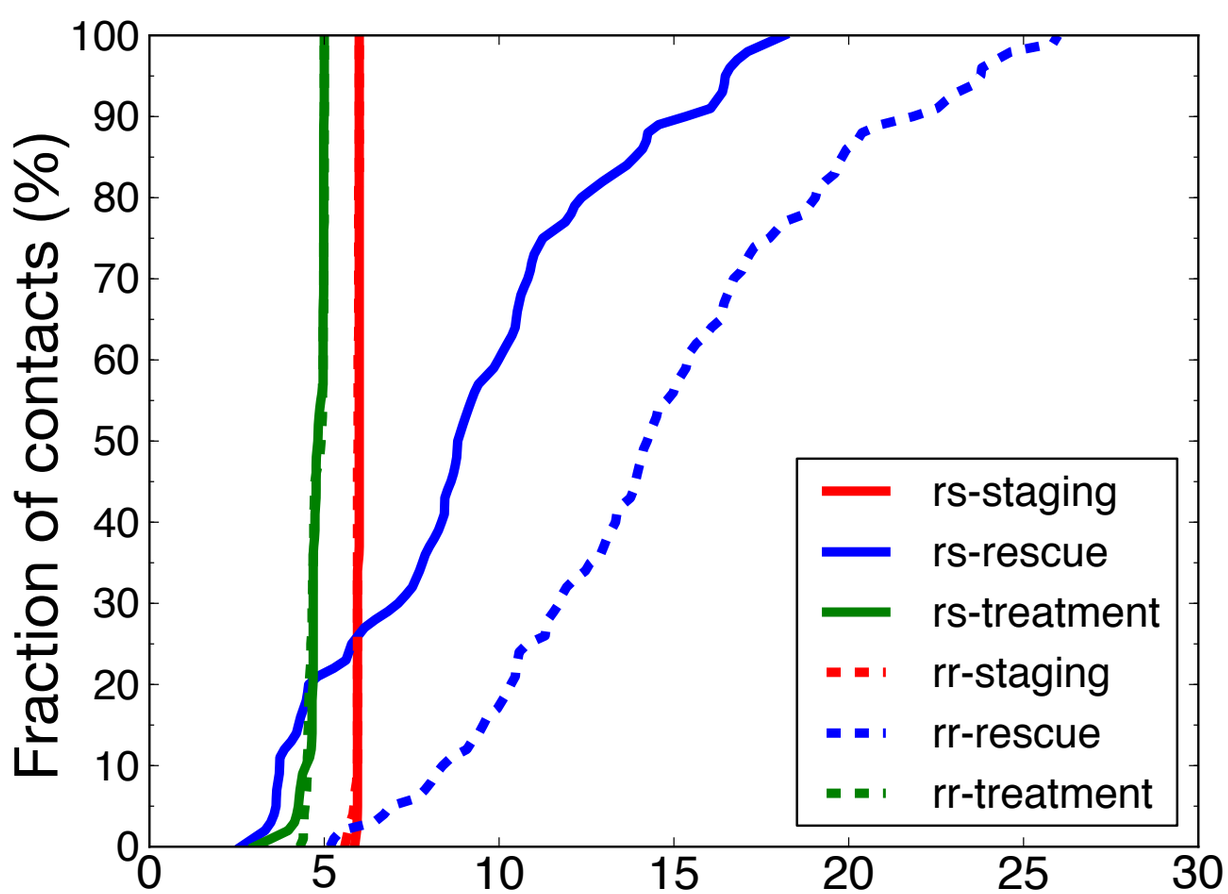
Feasibility of DTN-based emergency resp. systems?

- **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**

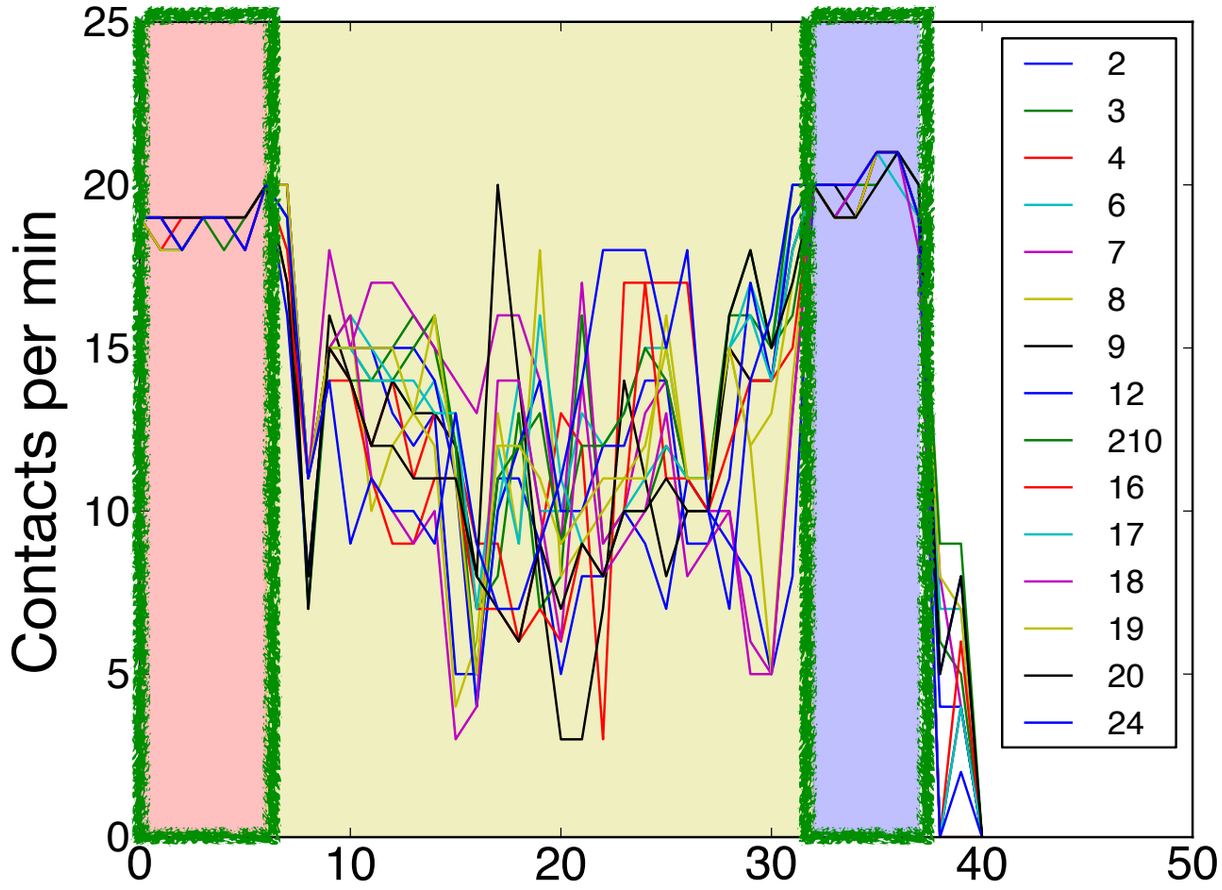
Link properties

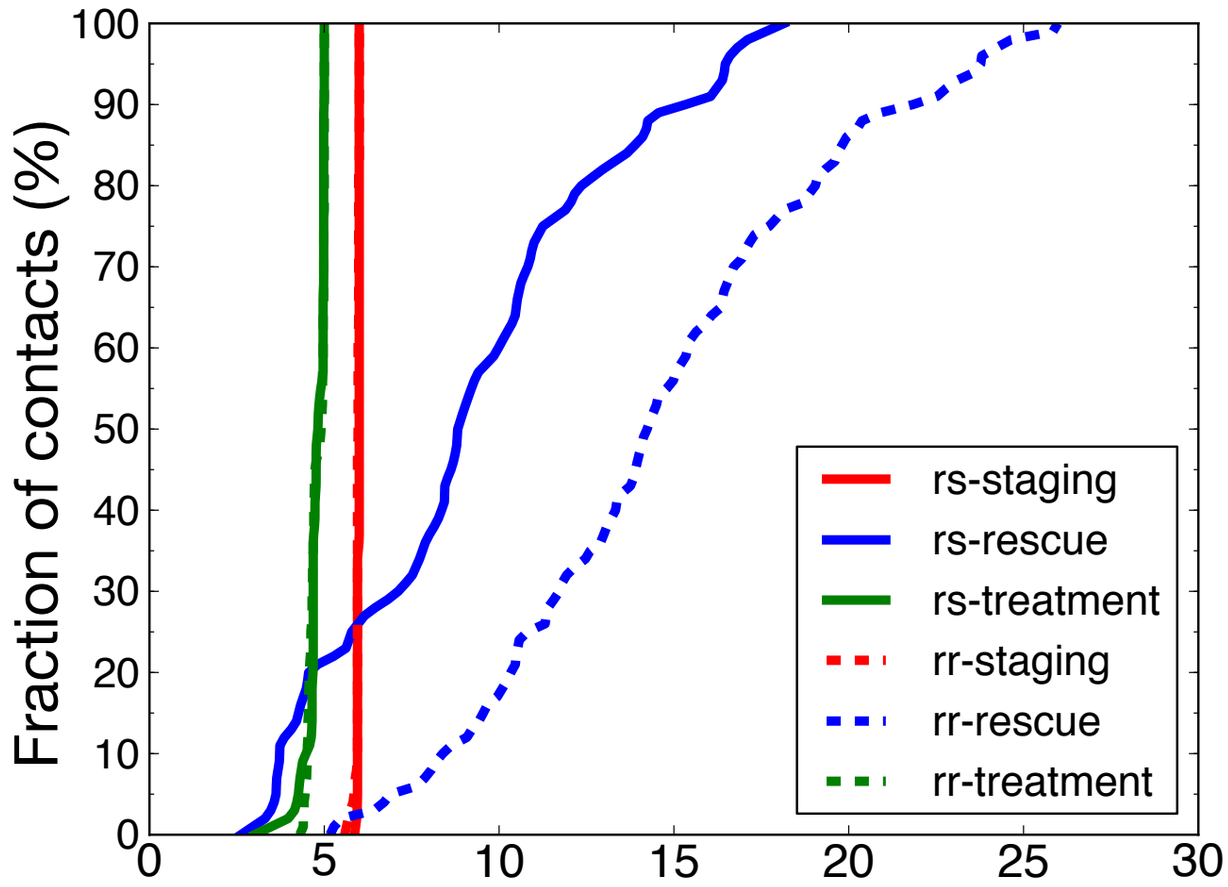




- **Link properties vary with drill phases**
  - high variability in the number of contacts during rescue phase
- **Long-term link properties depend on the roles of responder in the drill**
  - staging & treatment: good connectivity between responders and supervisors
  - rescue: poor connectivity between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

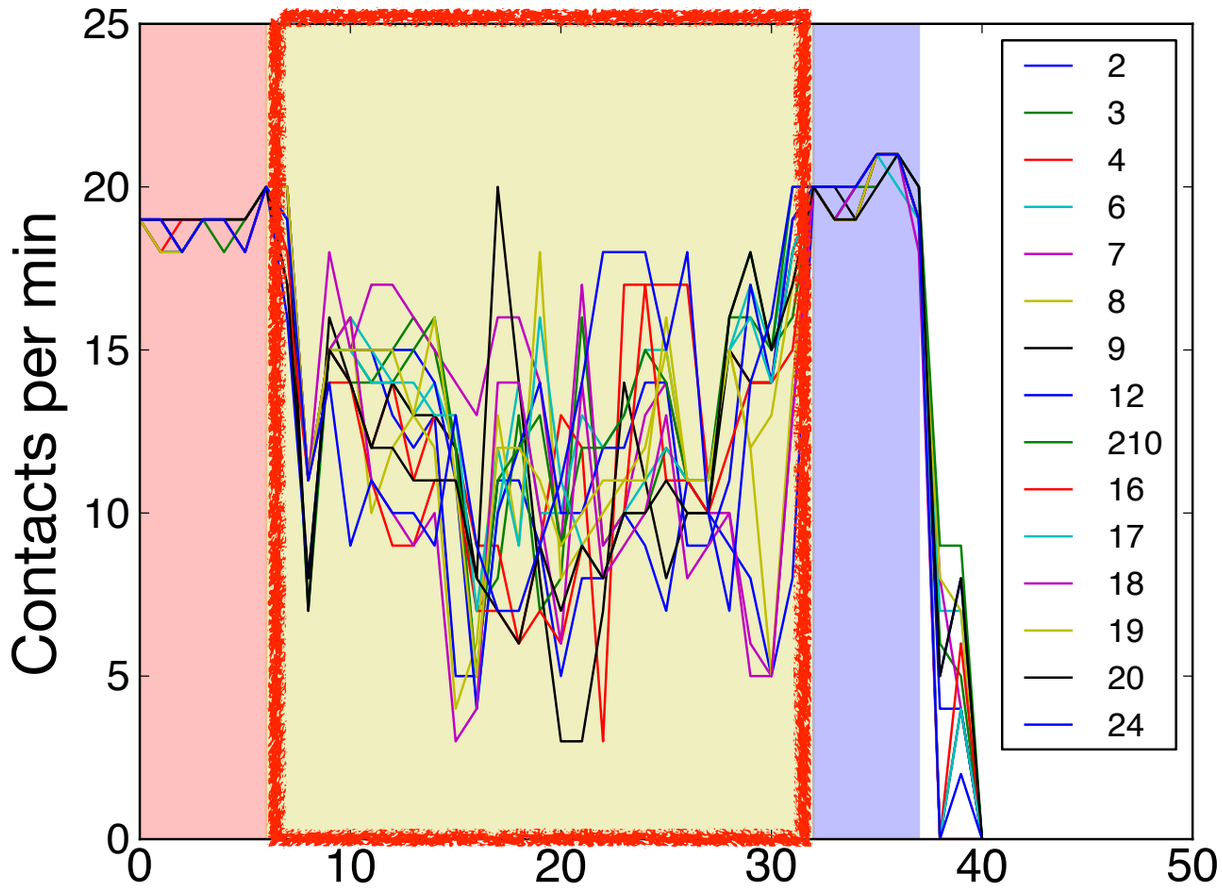
Link properties

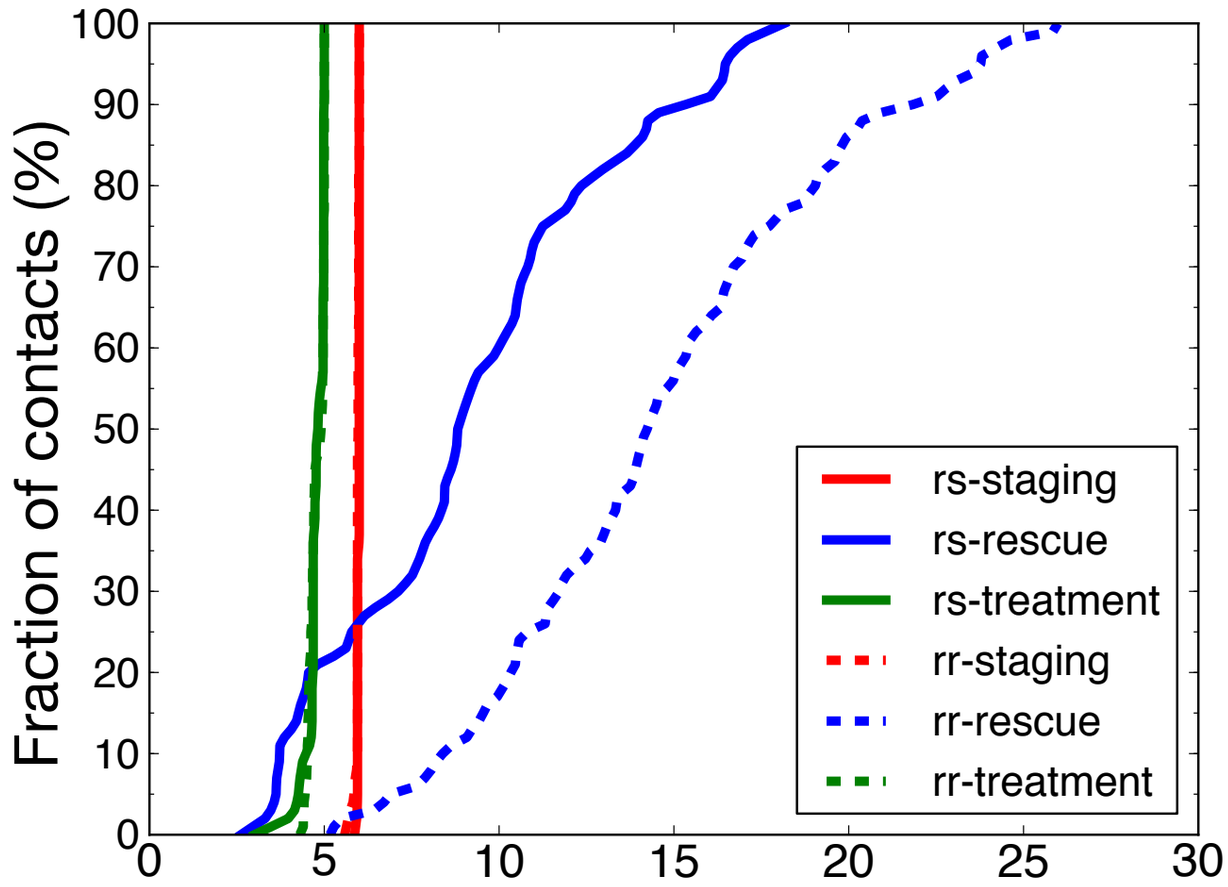




- **Link properties vary with drill phases**
  - high variability in the number of contacts during rescue phase
- **Long-term link properties depend on the roles of responder in the drill**
  - staging & treatment: good connectivity between responders and supervisors
  - rescue: poor connectivity between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

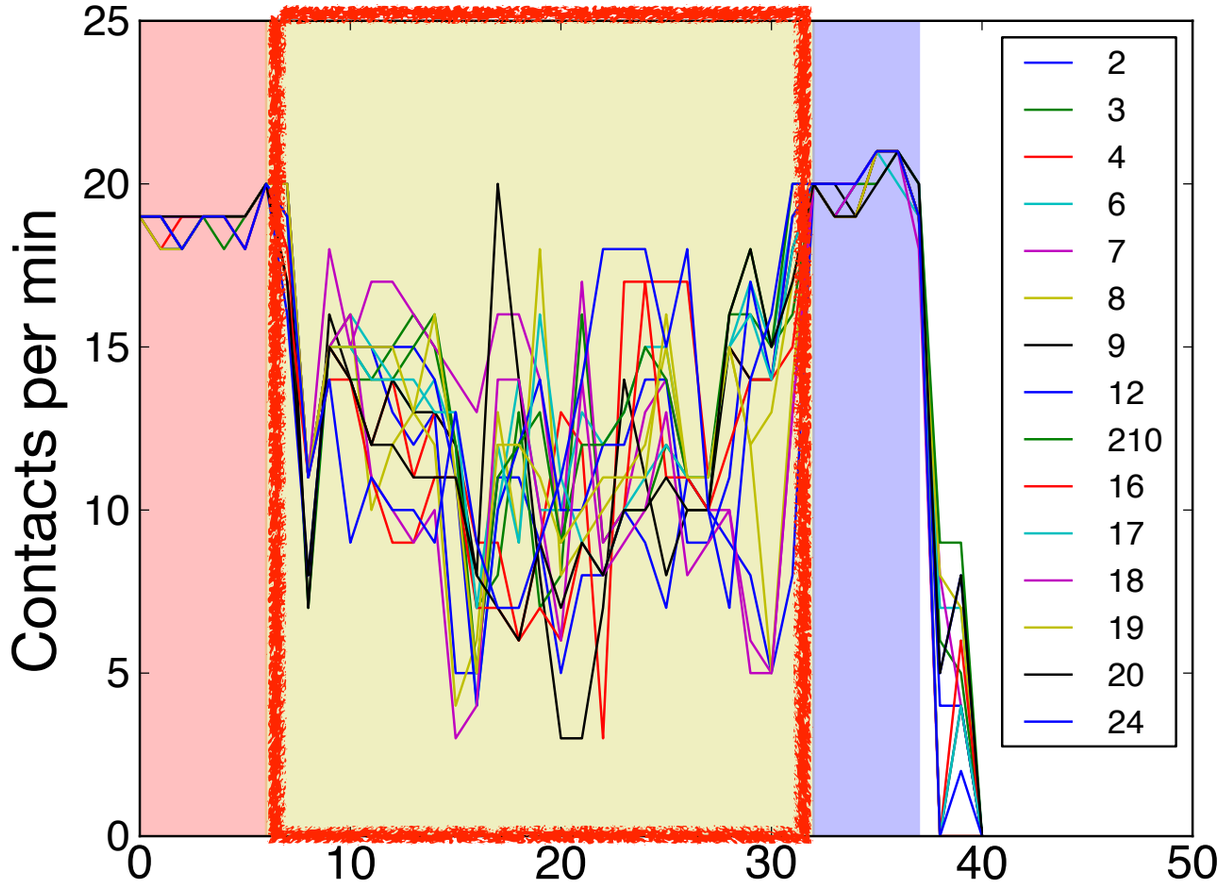
Link properties

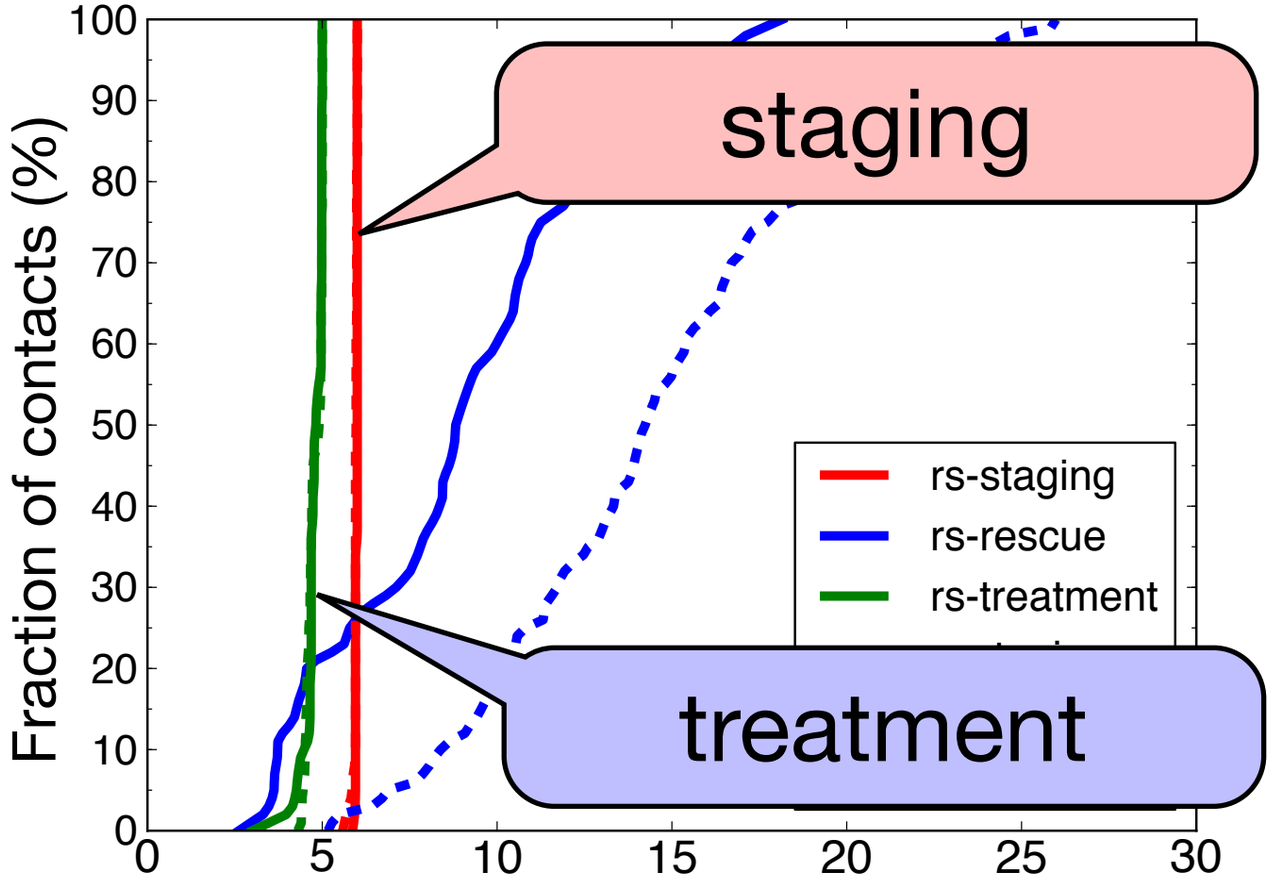




- **Link properties vary with drill phases**
  - high variability in the number of contacts during rescue phase
- **Long-term link properties depend on the roles of responder in the drill**
  - staging & treatment: good connectivity between responders and supervisors
  - rescue: poor connectivity between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

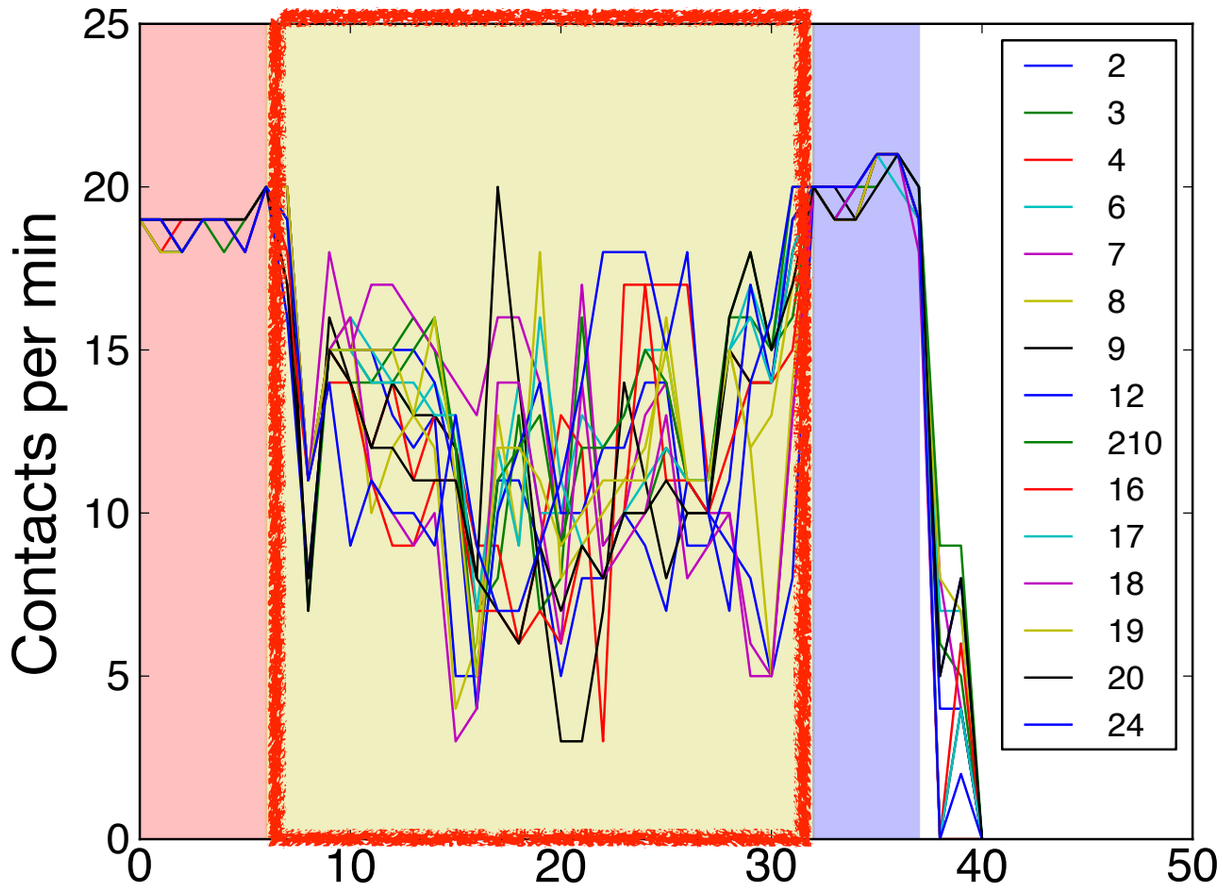
Link properties

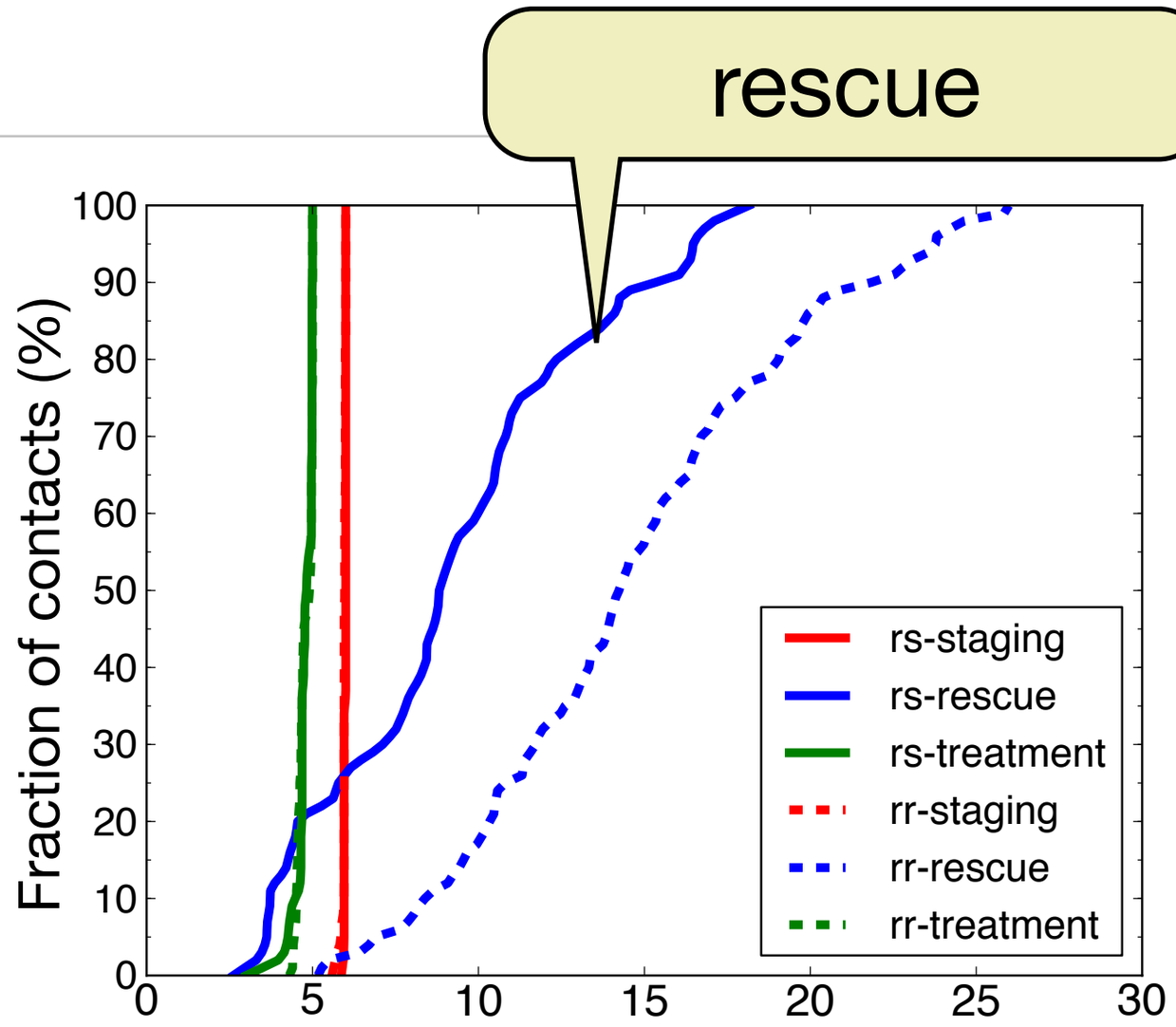




- **Link properties vary with drill phases**
  - high variability in the number of contacts during rescue phase
- **Long-term link properties depend on the roles of responder in the drill**
  - staging & treatment: good connectivity between responders and supervisors
  - rescue: poor connectivity between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

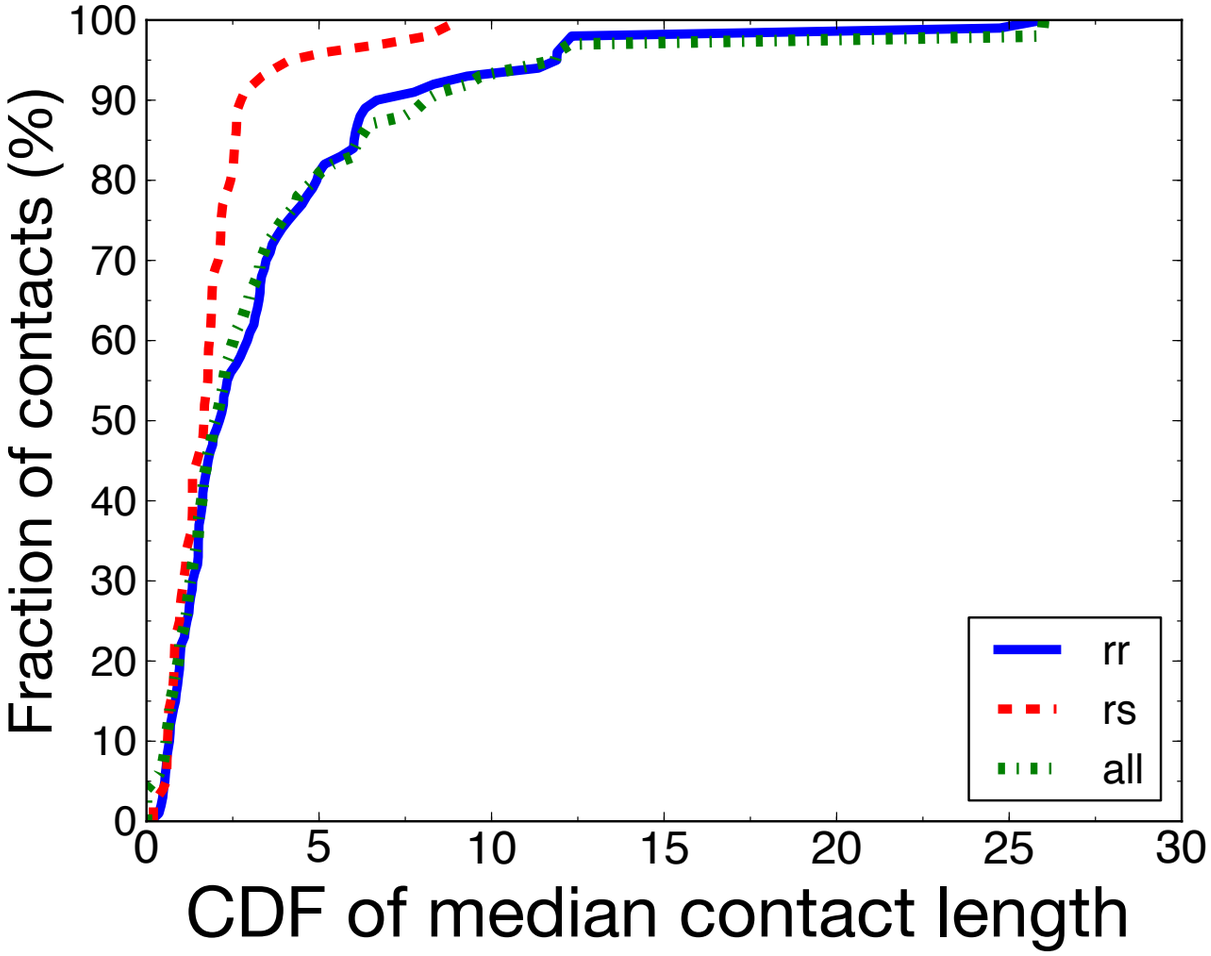
Link properties



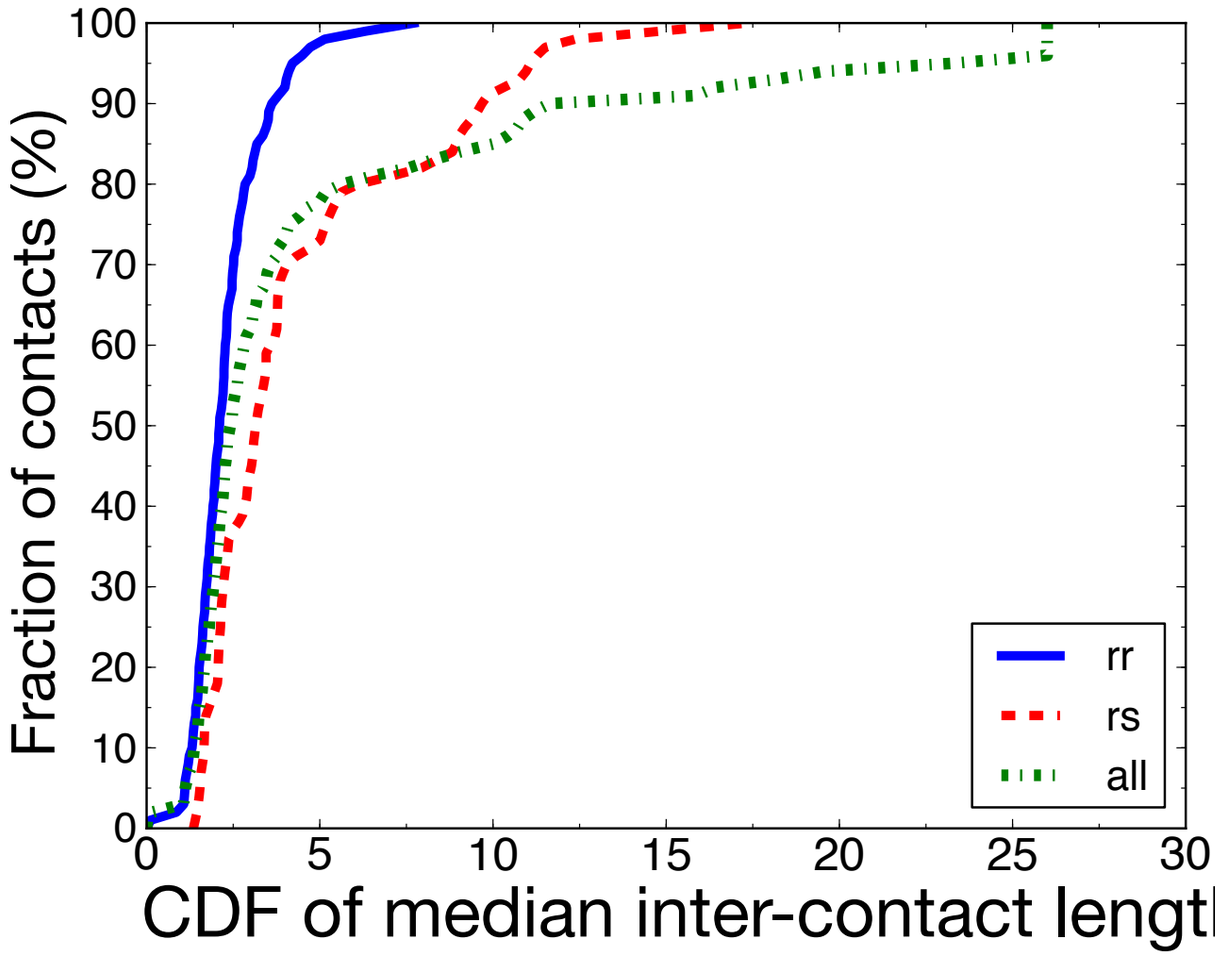


- **Link properties vary with drill phases**
  - high variability in the number of contacts during rescue phase
- **Long-term link properties depend on the roles of responder in the drill**
  - staging & treatment: good connectivity between responders and supervisors
  - rescue: poor connectivity between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

Contacts between responders during rescue phase



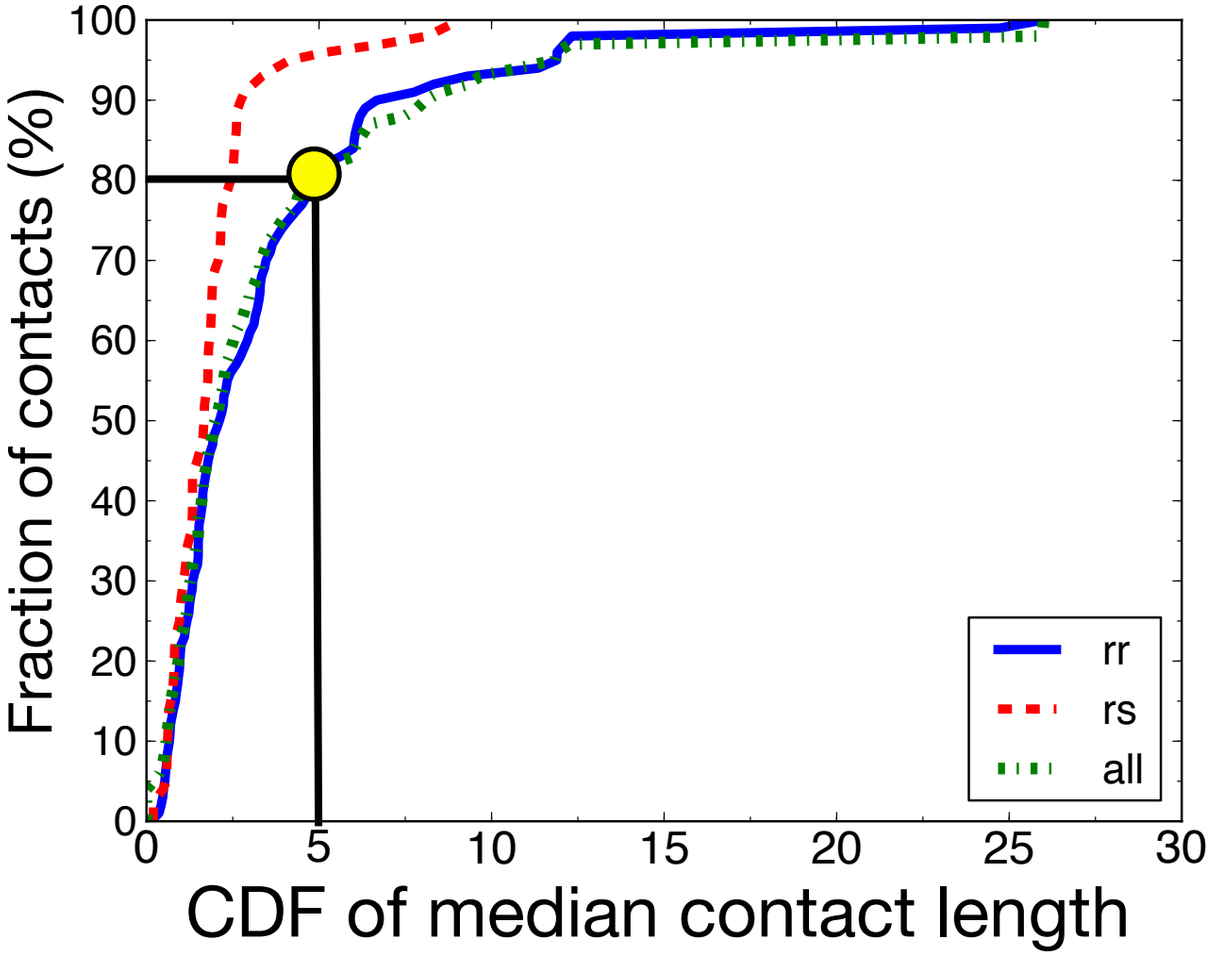
CDF of median contact length



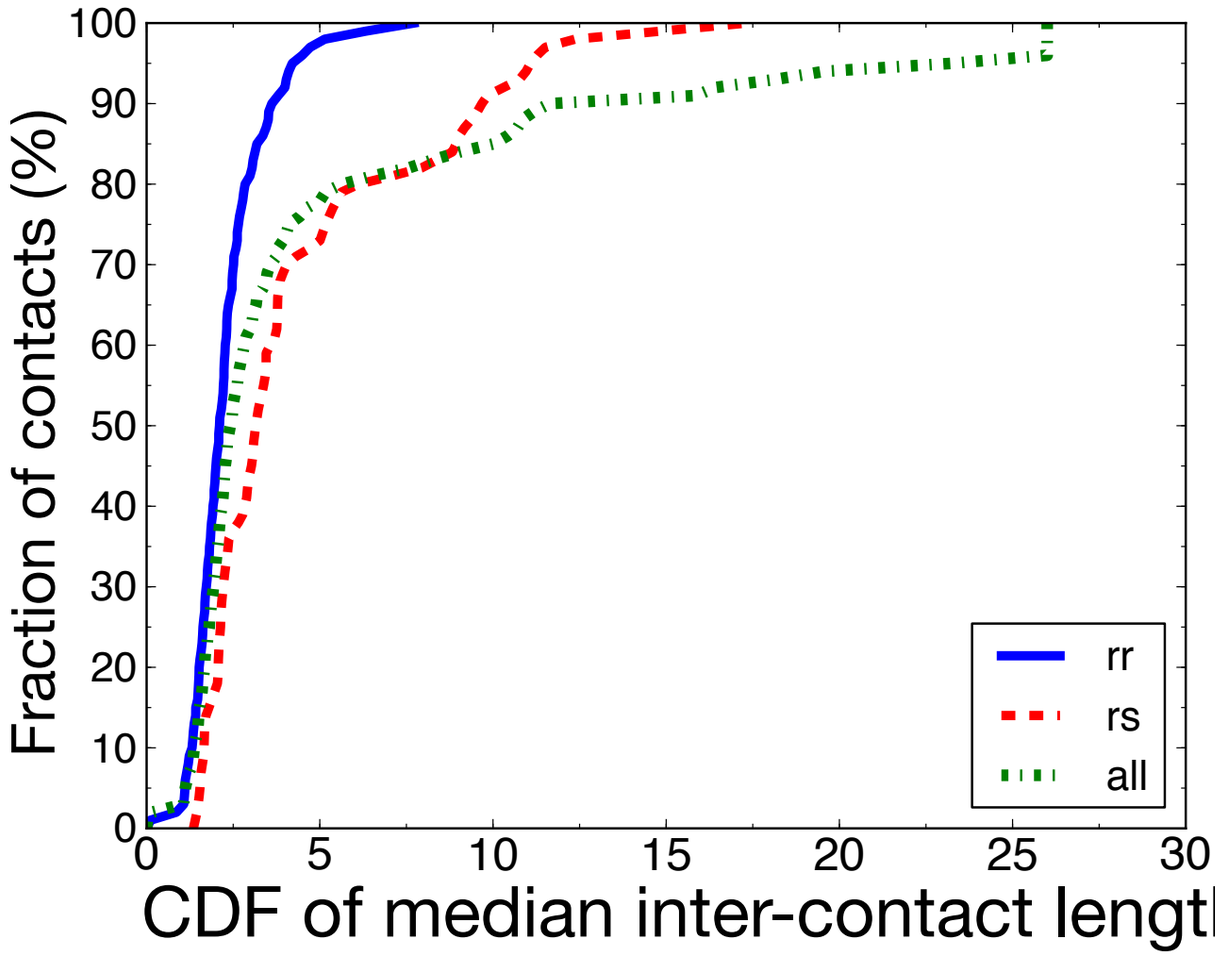
CDF of median inter-contact length

- **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



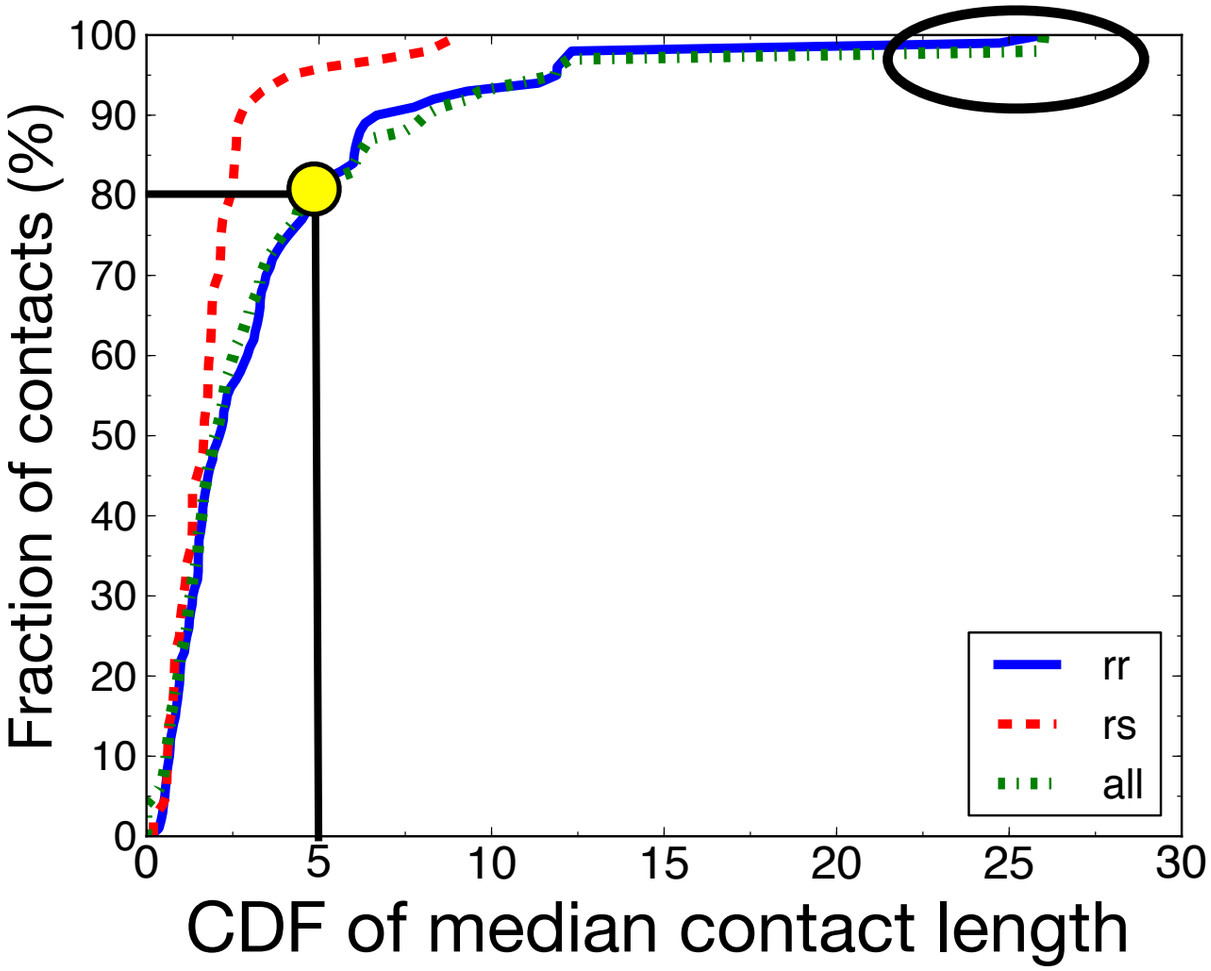
CDF of median contact length



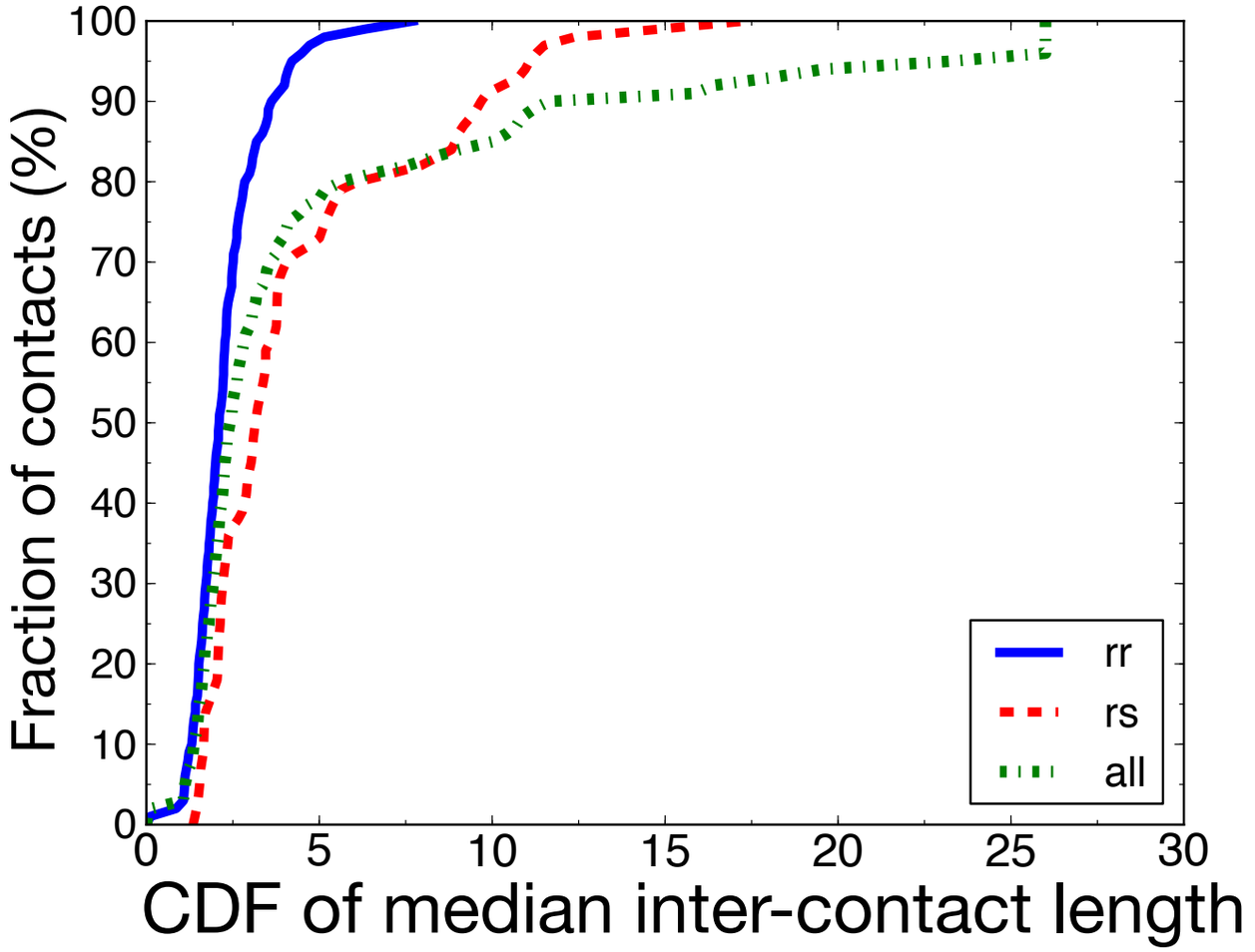
CDF of median inter-contact length

- **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



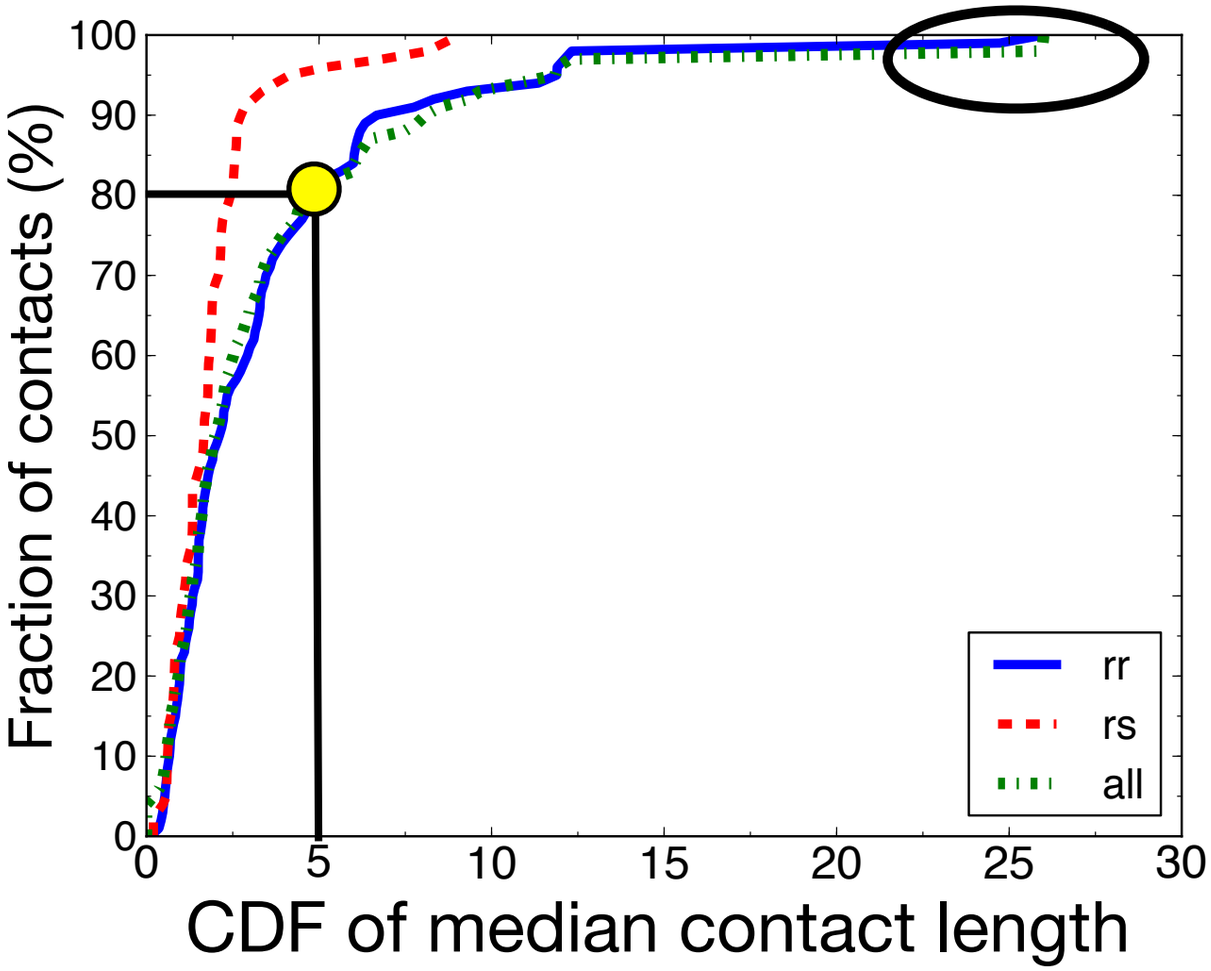
CDF of median contact length



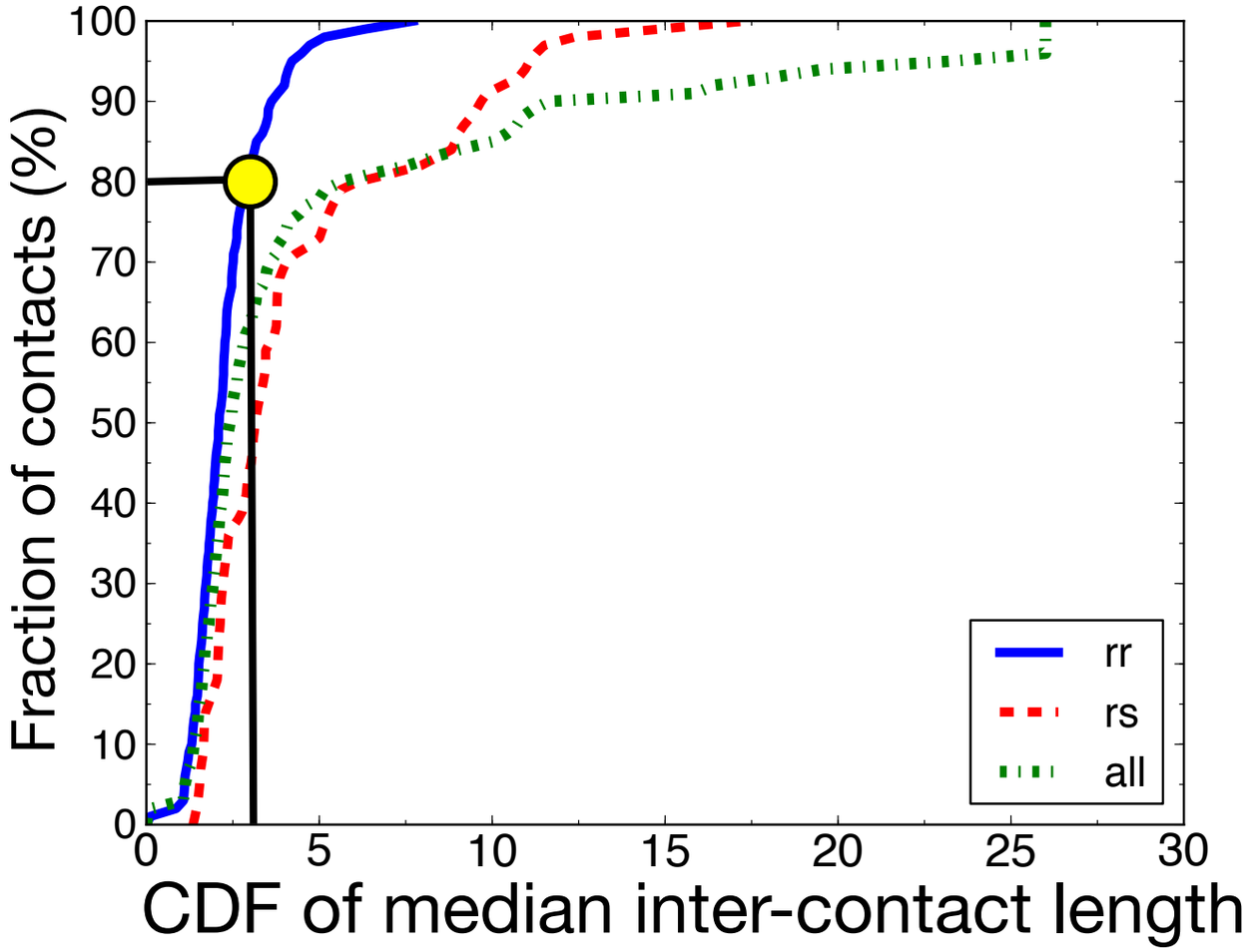
CDF of median inter-contact length

- **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



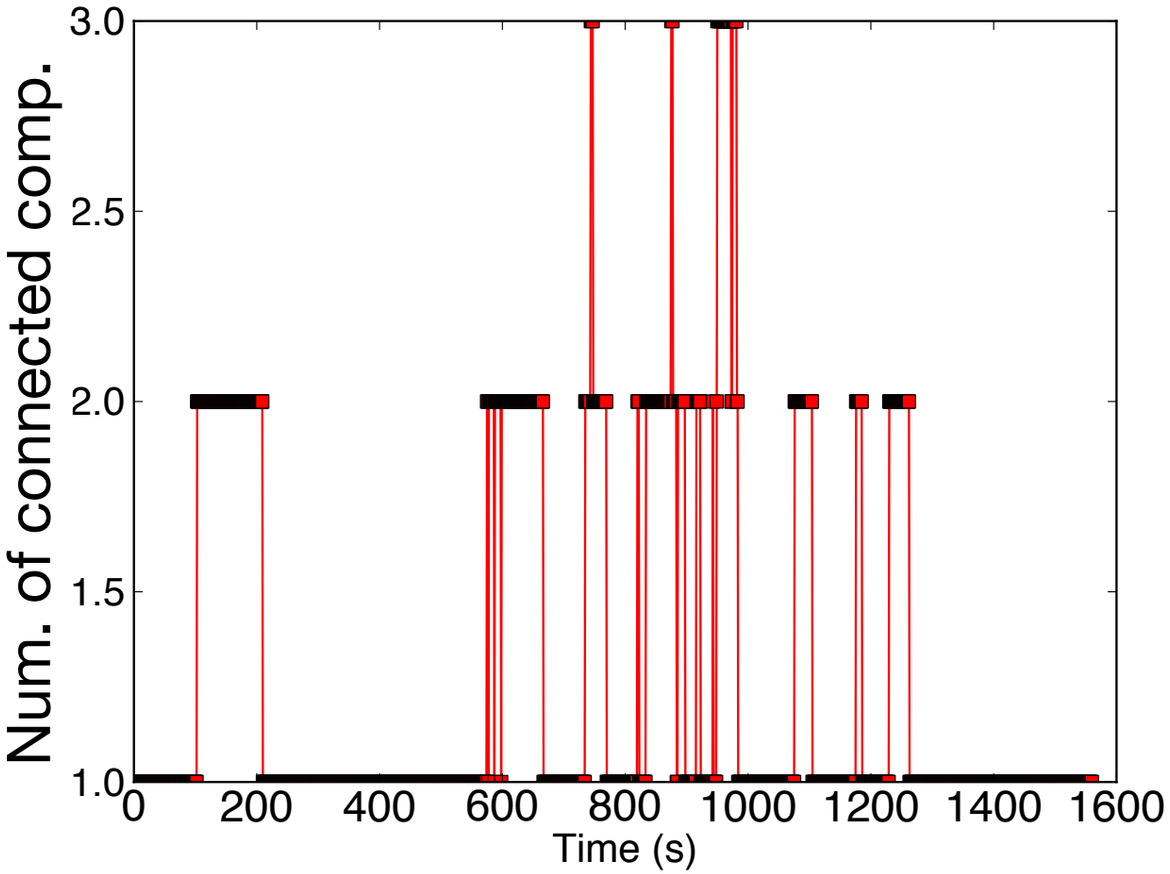
CDF of median contact length

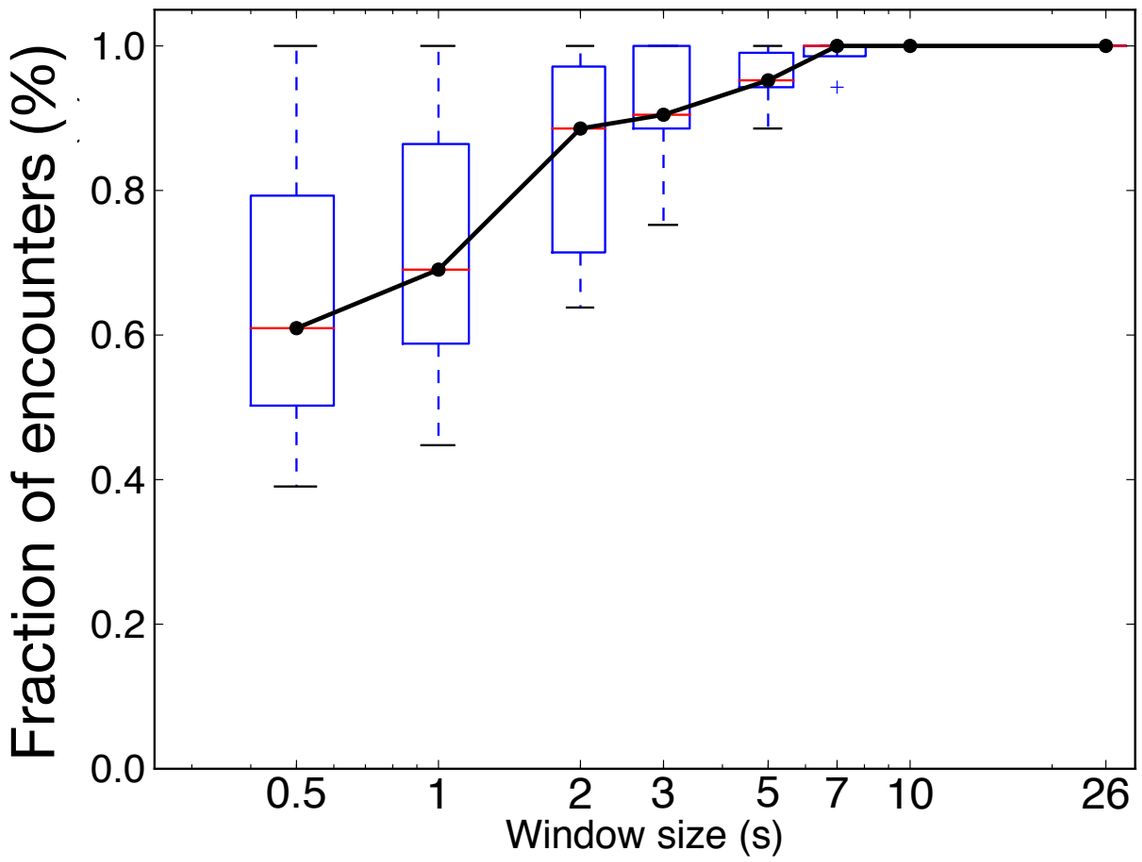


CDF of median inter-contact length

- **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**

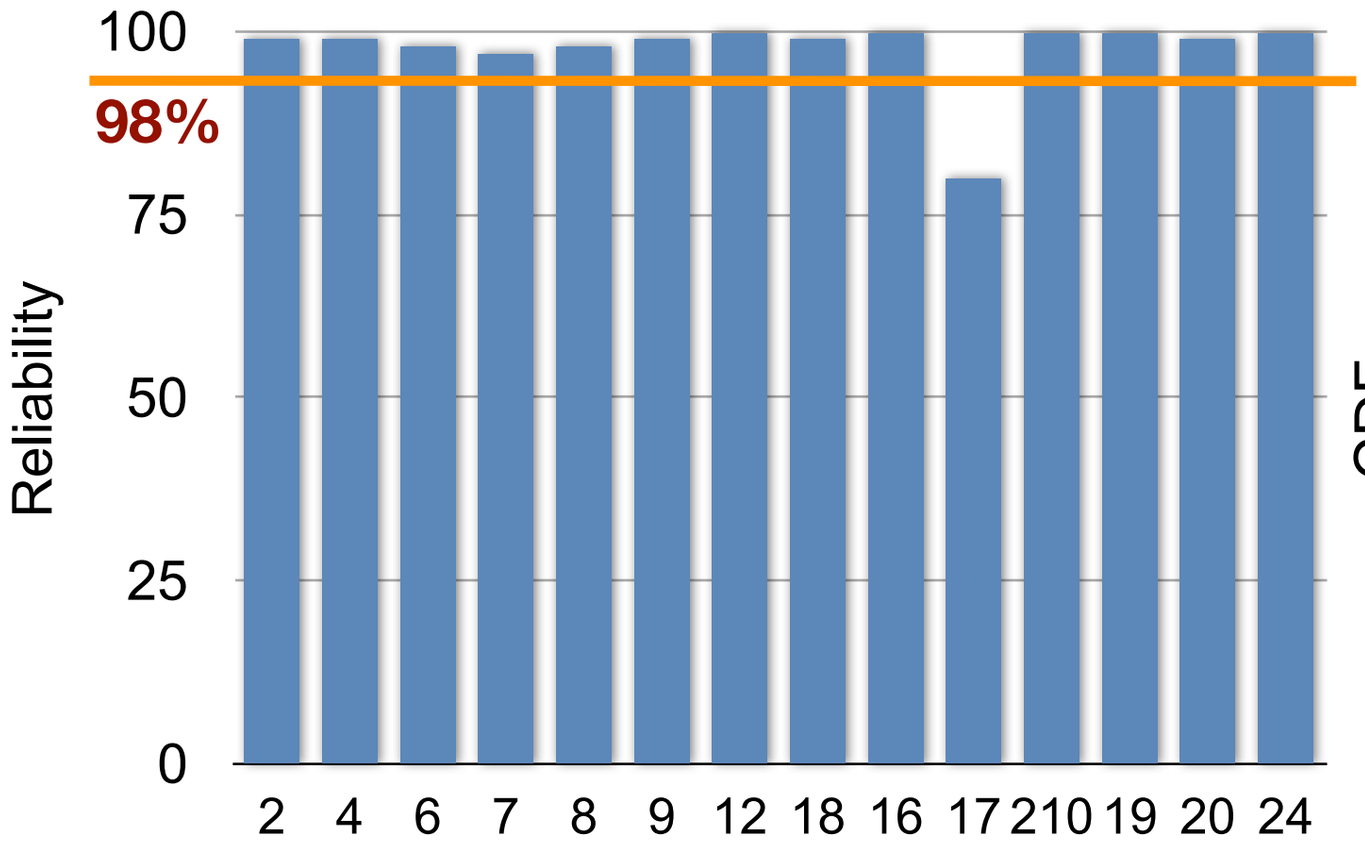
Network partitions and impact of mobility

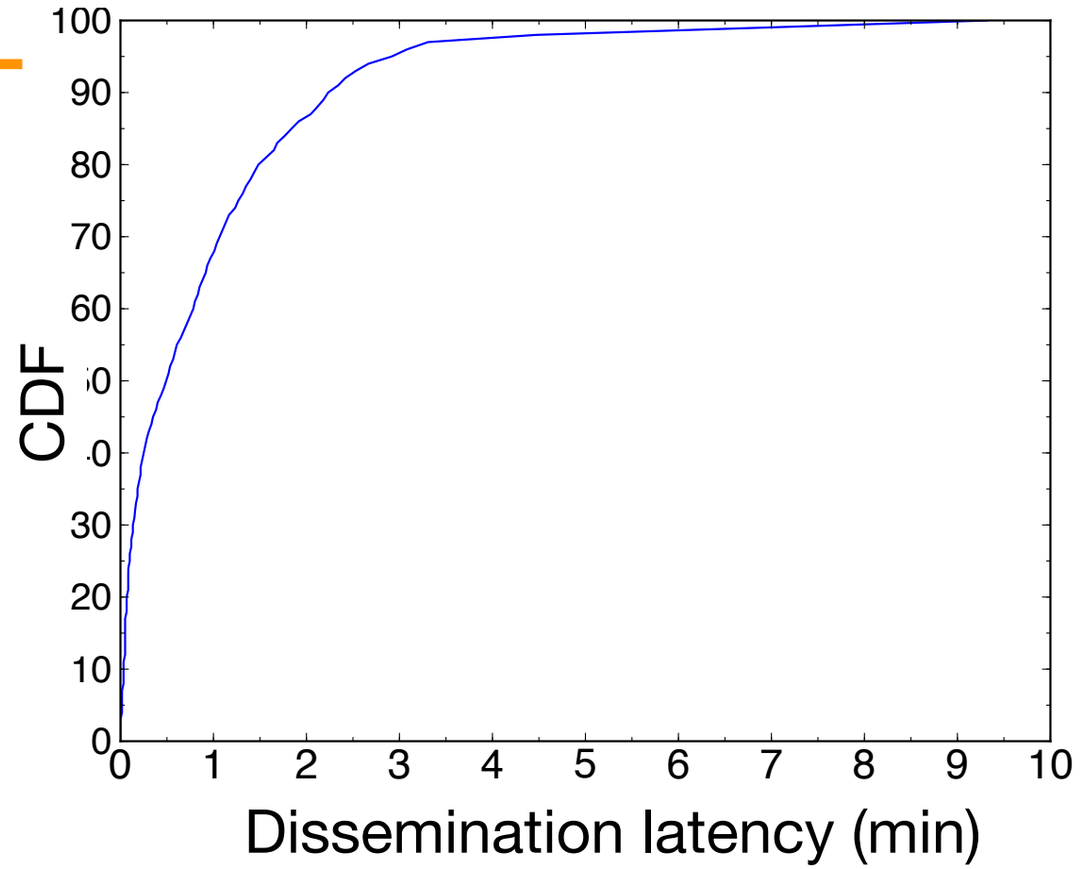




- **Partitions were common during rescue phase**
  - 26.3% of the rescue phase the network was partitions
- **Mobility helps disseminating data through data muling**
  - within 7 minutes a responder meets all other responders

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

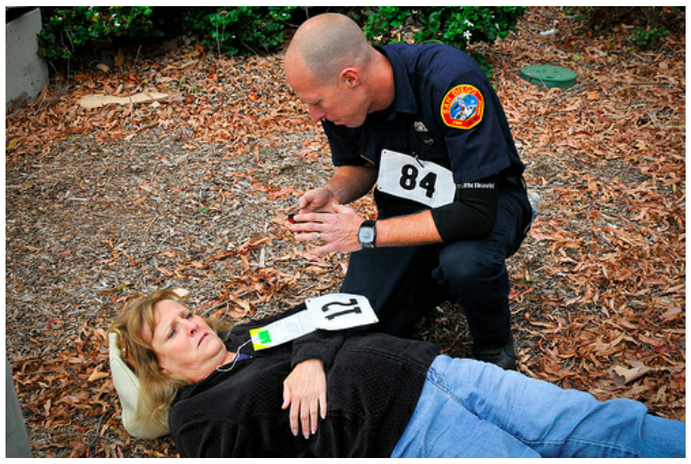
- **One of the first empirical studies of network properties during a drill**
  - **Incident Command Structure → network properties**
    - link properties vary with the phase of the drills
    - link properties vary with the role of the responders during the drill
    - network partitions are common
    - mobility significant improves dissemination of data
  - **validation from multiple drills required**

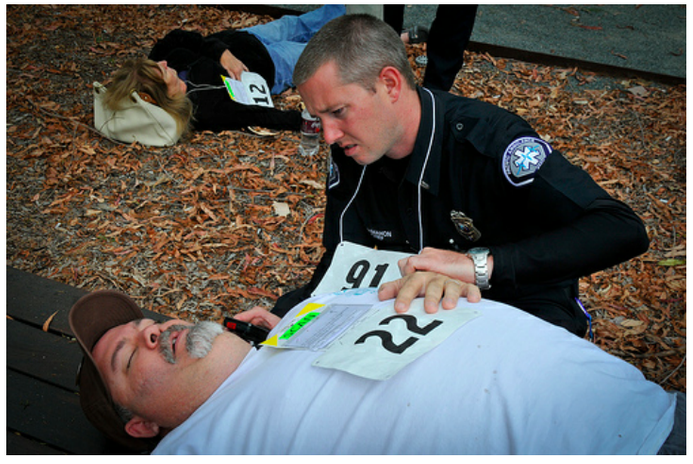
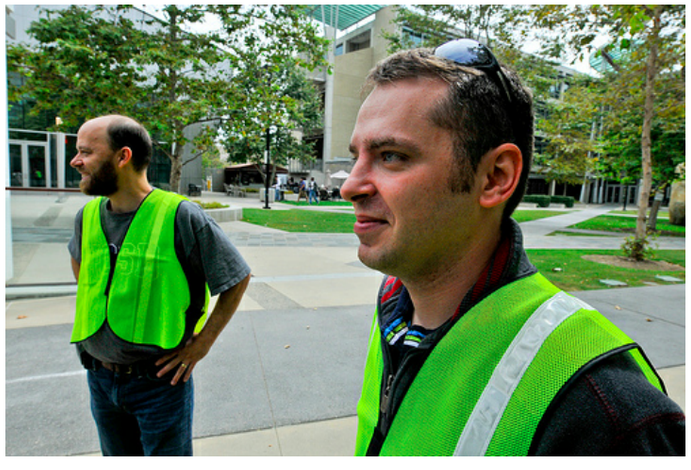
- **WIISARD - a reliable emergency response system**
  - 98% median reliability, 95% of data disseminate within 2.5 minutes
  - shows the feasibility of DTN techniques in emergency response systems

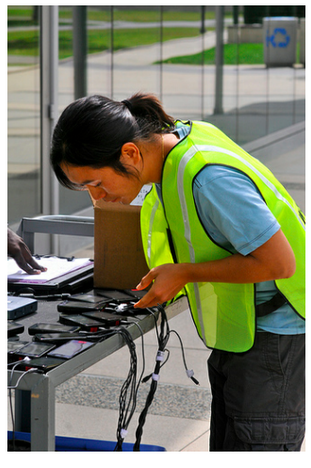
- **On-going: simulator for evaluating emergency response systems**
  - use the Incident Command Structure as a generative model

Acknowledgements

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



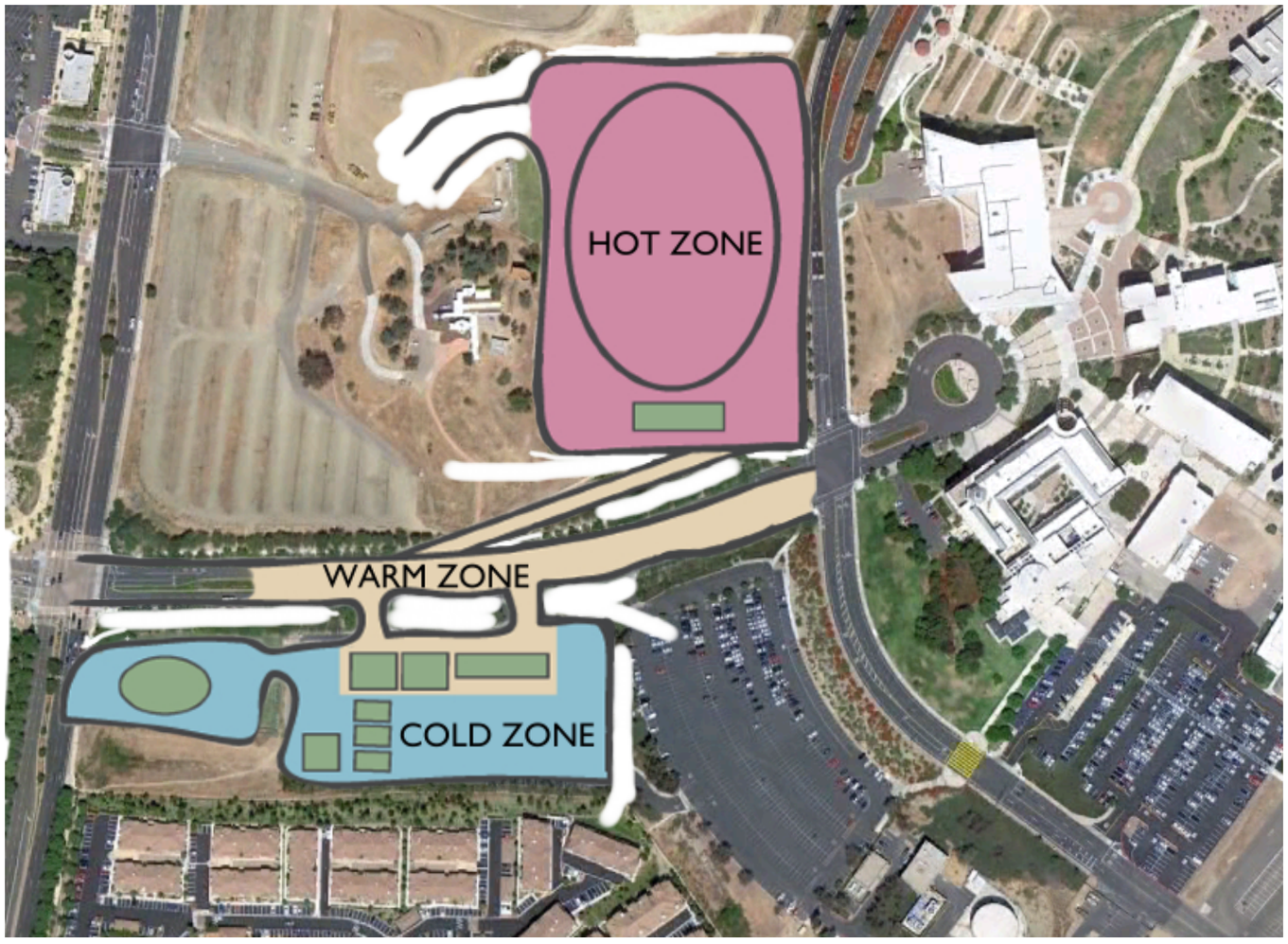



Questions?

Incident command structure (ICS)

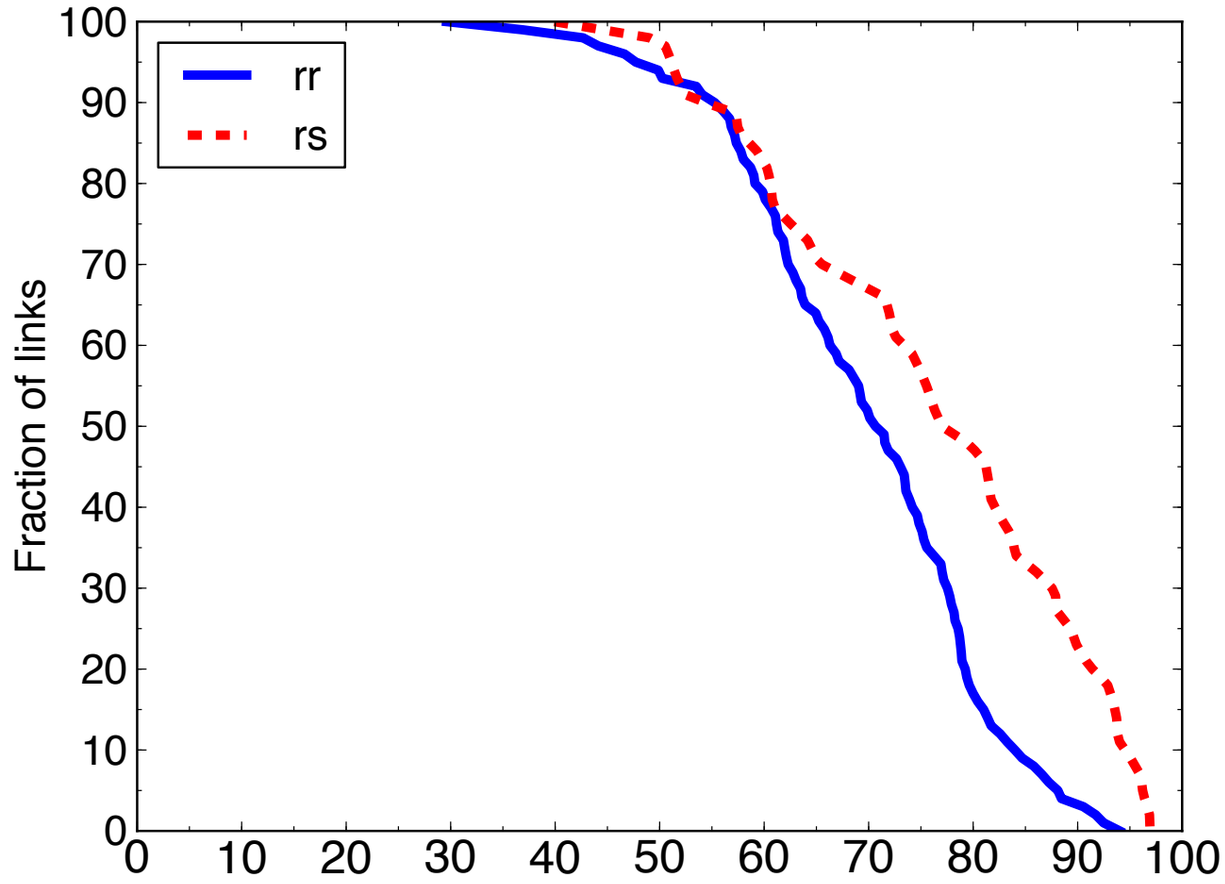
staging → rescue → treatment → transport

Incident command structure (ICS)



staging → rescue → treatment → transport

Link quality during contacts



CDF of PRR during contact length

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