HELP FROM THE SKY: LEVERAGING UAVS FOR DISASTER MANAGEMENT

Sedef Savas

February17th, 2016

Netlab Friday Group Meeting

Control Plane Mapping Problem

Design a resilient control plane that satisfy latency constraints.

A distributed control plane can be designed as an overlay (i.e., virtual/logical) network mapped over a physical (i.e., backbone) network.

- virtual nodes where controllers are located and virtual links connects them.

We propose a survivable control plane mapping scheme to ensure control-plane connectivity against both single point of failures and large-scale disaster failures in SDN.

Problem formulation

Given: Topology, Datacenter locations, Disaster size

Objective

Find minimum # of controllers, place them, connect them, assign switches to them.

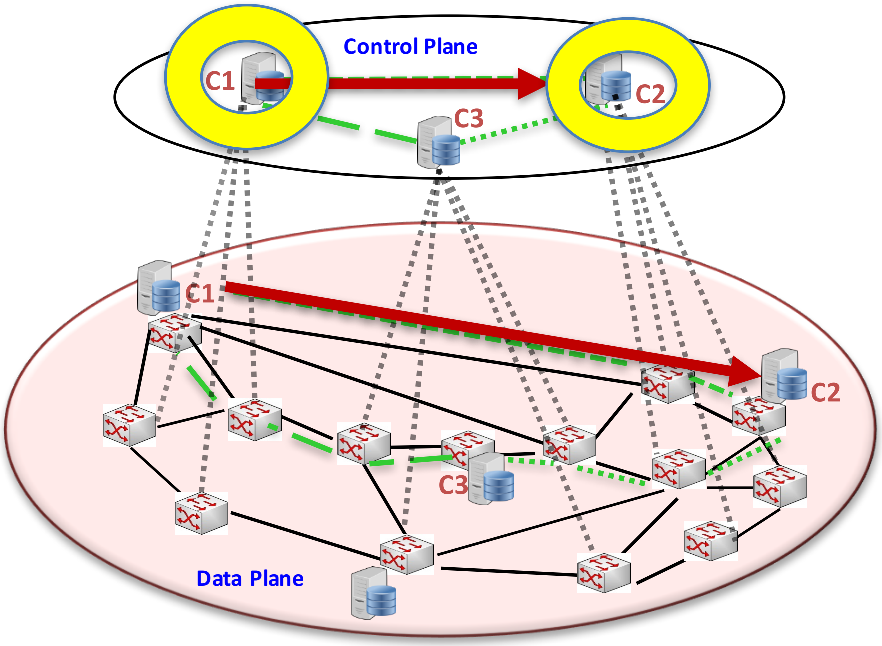
Constraints

Latency requirements: Limits worst case.

1. Maximum latency between switches and controllers.
2. Maximum latency between any controller pair, affects synchronization time.
3. Maximum path setup latency.

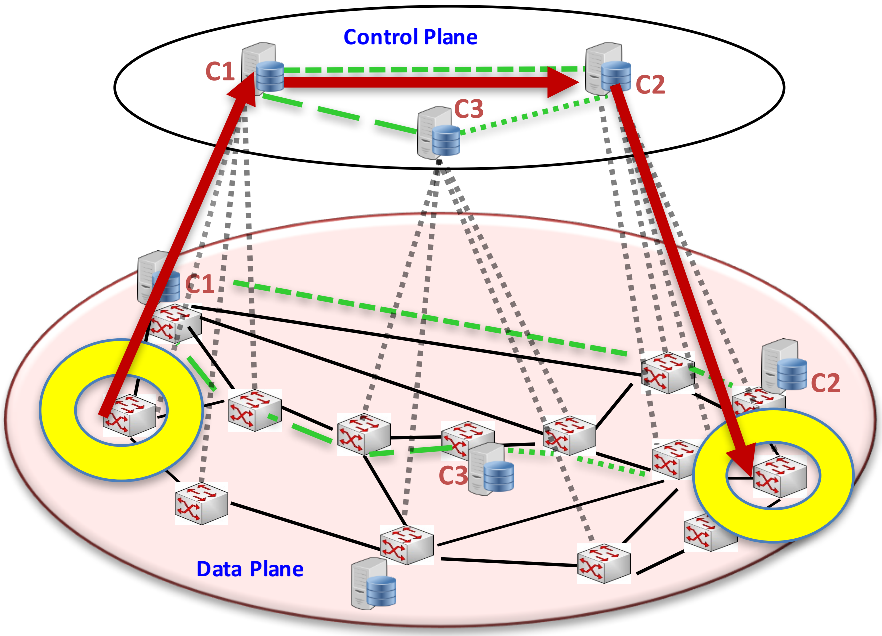
Switch controller latency's affect: For all possible disasters, after failure, make sure there is a path to a controller within latency limits. This will be preprocessed.

Synchronization latency



Periodically, flooding state updates.
Not every controller sends every other controller the same info.

Worst case path setup latency



Controllers: close to switches or other controllers?

Switch-controller communication:

- Periodic state update
- New flow setup

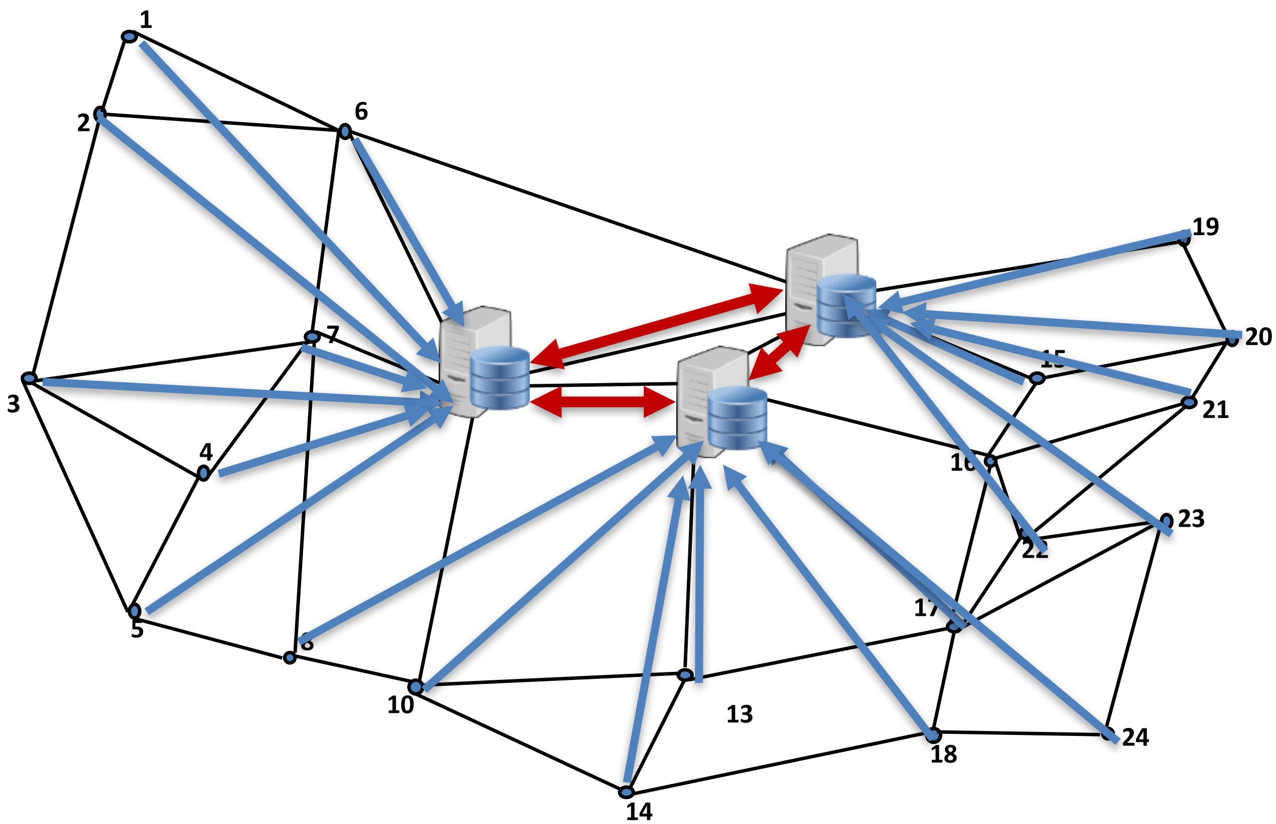
Controller-controller communication:

- Synchronization
- New rule installation requests

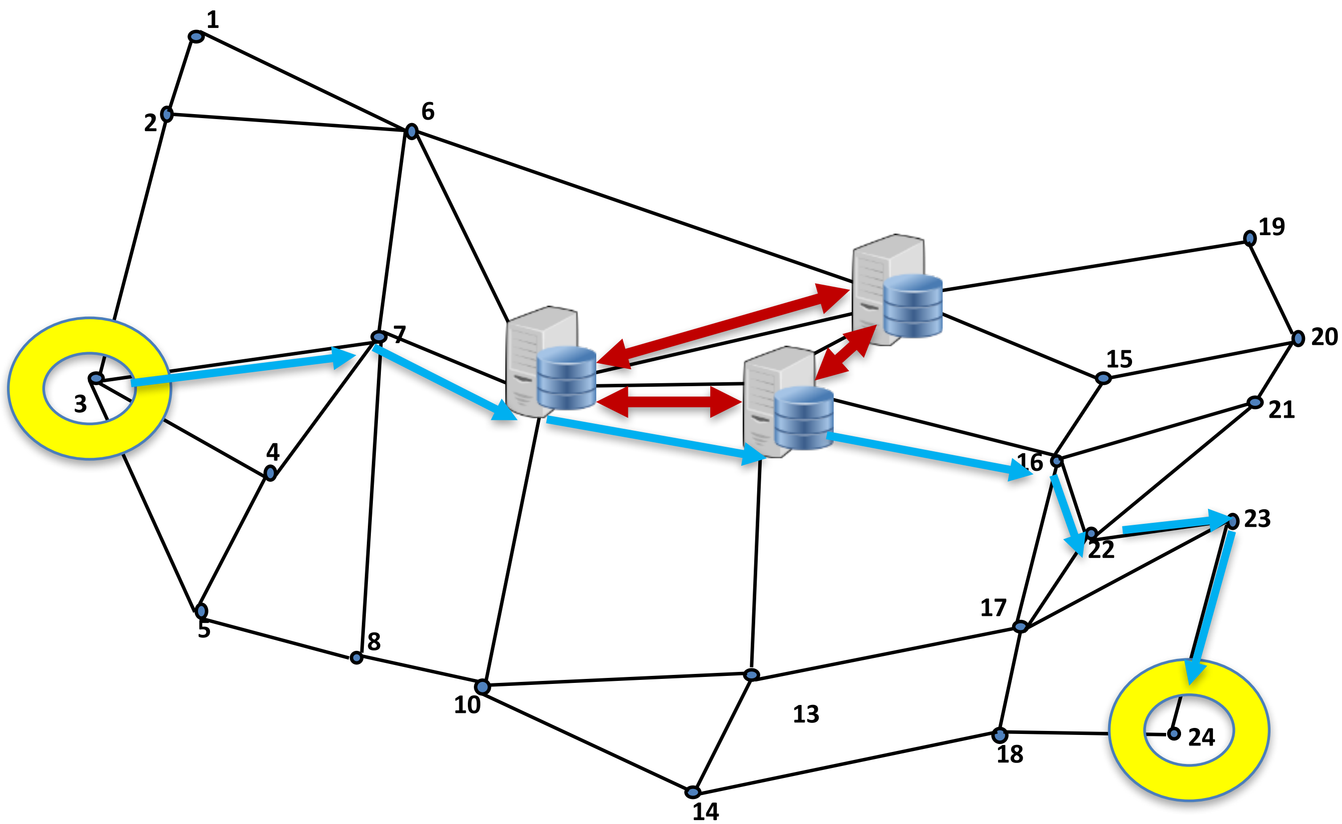
Depends on the topology and constraints:
Many switches connect to a single controller: Controllers should be closer to switches in many switches with high loads scenario. More flows do not need to be sent to other controllers, but routed within the cluster. Decrease flow setup latency.

If not much can be gained from placing controllers apart, then place them close. Decrease synchronization.

Close to other controllers

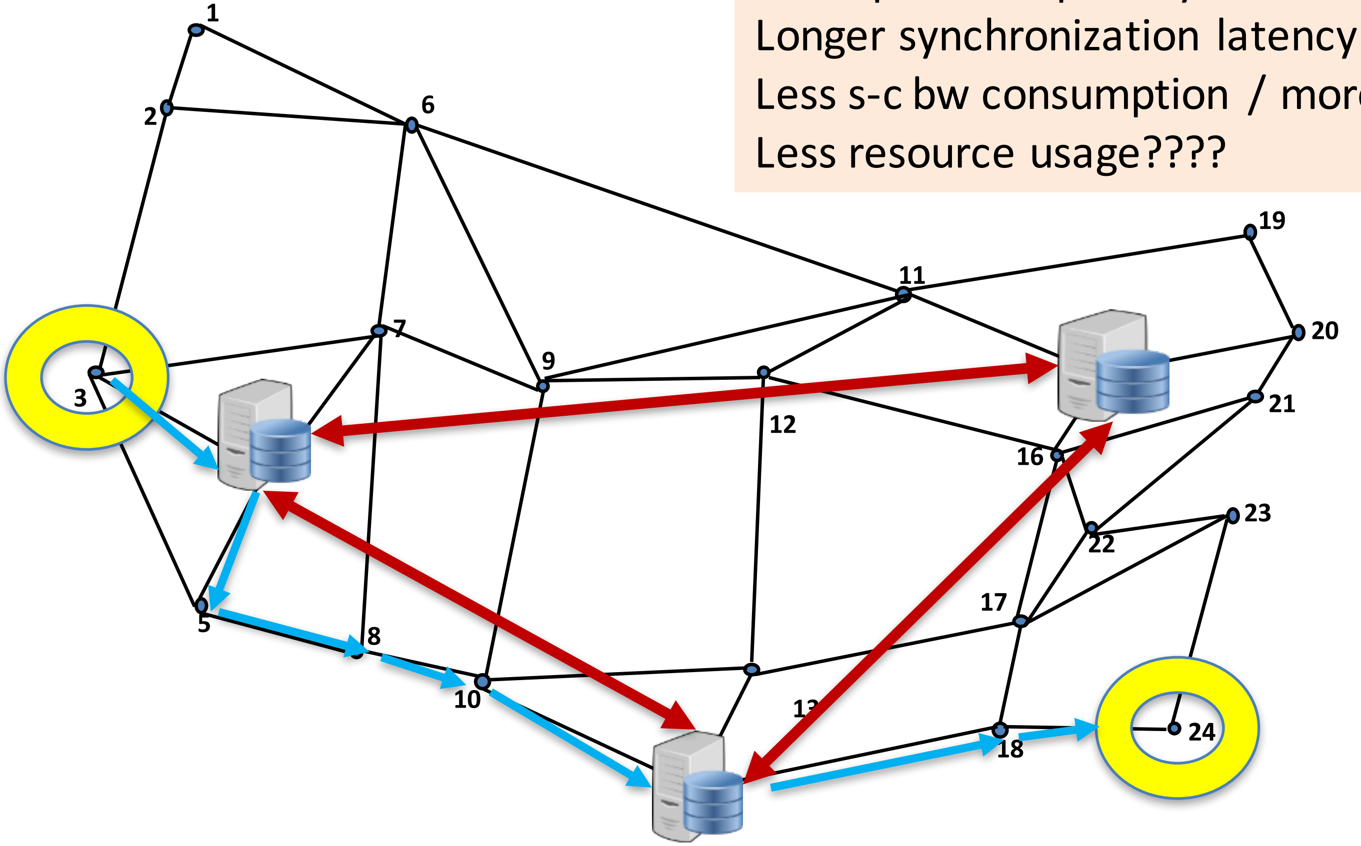


Close to other controllers

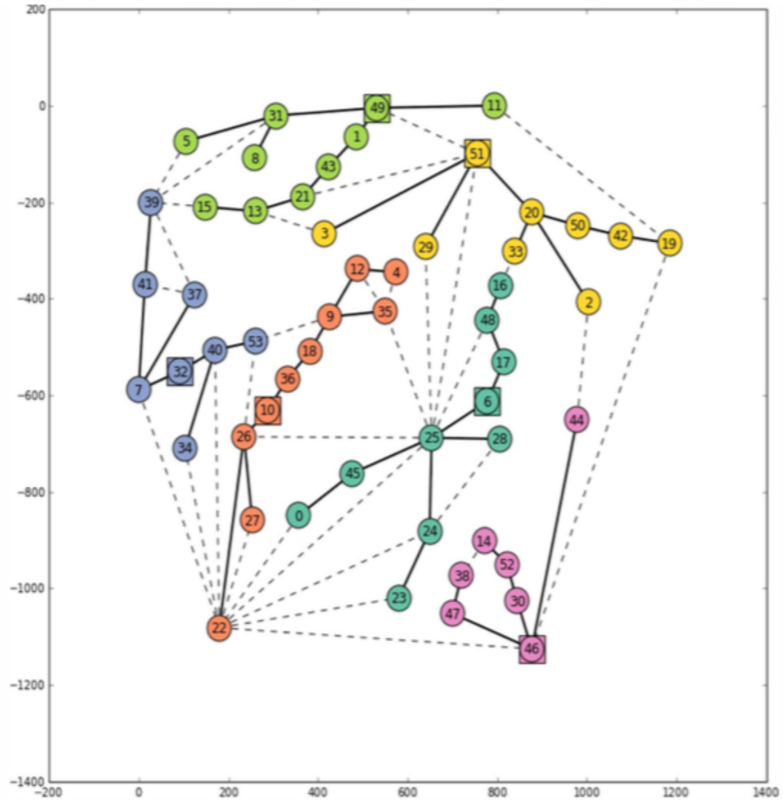


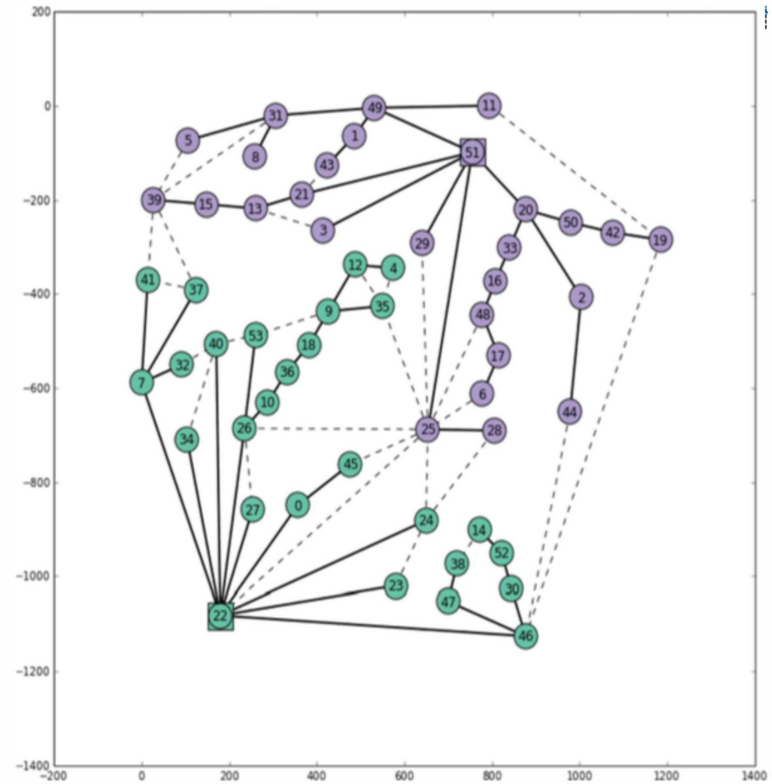
Close to switches

Same path setup delay
Longer synchronization latency
Less s-c bw consumption / more c-c (negligible)
Less resource usage????



Max latency between router-controller(30% of the graph diameter) and controller-controller (70% of the graph diameter) is set.





ig. 6. Optimal solution with $l_{max} = 30\%$, $l_{cc\text{-}max} = 70\%$ and $\delta = 3$

Fig. 7. Optimal solution with $l_{max} = 50\%$, $l_{cc\text{-}max} = 70\%$ and $\delta = 3$

TABLE I. SENSITIVITY ANALYSIS OF THE CONSTRAINTS ON THE OPTIMAL SOLUTION

l_{max}	$l_{cc\text{-}max}$	δ	Placement
0.4	0.7	3	4 21
0.3	0.7	3	9 18 21 28
0.27	0.7	3	2 4 11 26 28 34
0.25	0.7	3	2 9 18 22 23 24 26 30
0.35	0.4	3	$\emptyset$
0.35	0.7	3	10 19 22 29
0.35	0.9	3	14 16 19 32
0.35	1	3	2 5 8 9
0.35	0.7	1	2 3 5 9
0.35	0.7	7	6 9 28
0.35	0.7	15	6 31 35

Constraints (cont.)

Capacity requirements

Datacenters have capacity limit. Each controller will be responsible of a limited # of nodes.

Resiliency/Connectivity requirement:

- Control plane resilient against single point of failures. At least 2-connected. Depending on the disaster range and the topology more may be needed.
- After any disaster at size r, alive controllers stay connected. And all switches can be assigned to a switch within latency constraint.
- Initially, at least 2 controllers within latency requirement of switches to achieve these.

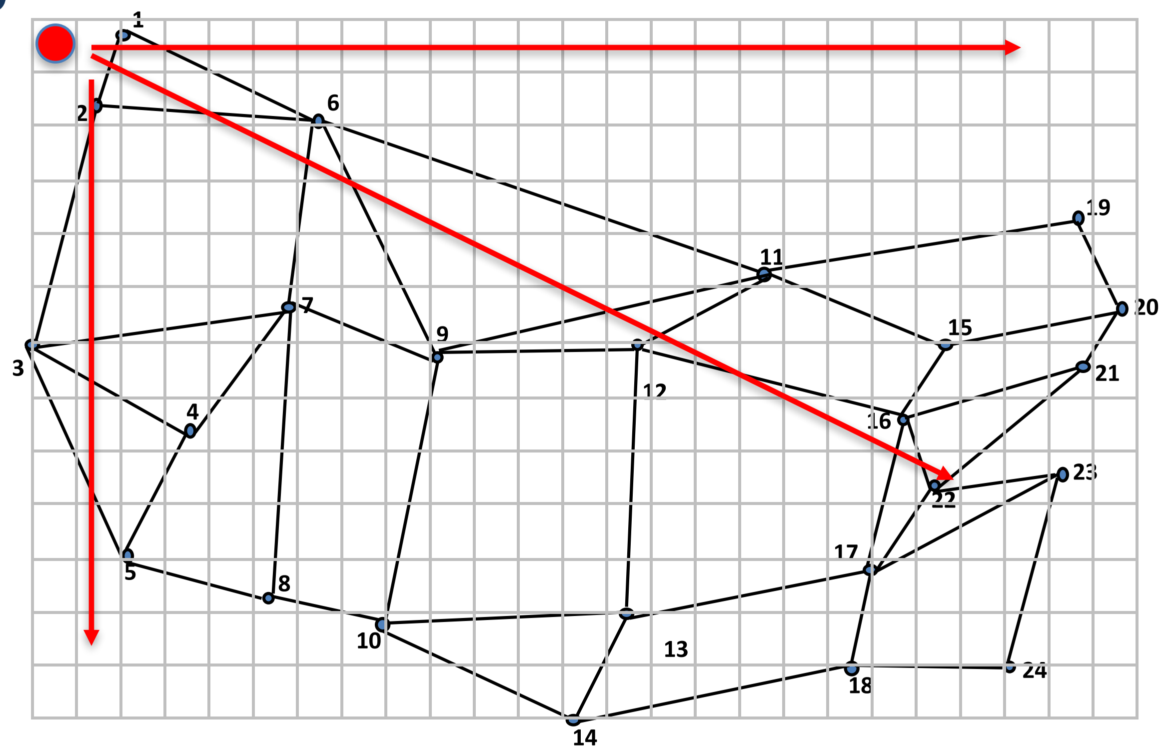
Assumptions

- Uniform demand.
- Only specific nodes can be controller locations.
- Each router to exactly one controller.
- All switches being controlled by their nearest controller and all control paths being the shortest paths between the switch and the assigned controller.

- Do not consider backups between switches and controllers. As long as control plane is up and physical layer is connected, control plane will reach unattached switches. **Hard to find disjoint paths that will survive all r-sized disasters.**

Do not consider reassignments in case of disasters, one disaster at a time, no need to consider normal mode of op. constraints (only latency), so not much to show. **Design problem.**

Modeling disasters



Algorithm

Many components of the problem is NP-Hard.

- CPP reduces to a Facility Location Problem and is proved to be **NP Hard.**
- VNE is NP-Hard.

Decomposition technique based heuristic algorithm: to reduce the computational complexity

The main idea of our algorithms is to decompose the primal problem into |R| sub-problems and solve these sub-problems separately.

For VNE: this means, the mapping for virtual nodes and links are completed in ordered phases.

1. For each node, find the set of nodes within reachability circle.

2. Find list of minimum nodes that must exist in the VN, considering each switch need 2 closeby controllers, considering capacity requirements. Minimal set cover. Sort those list acc. to number nodes that must be in the VN.

3. Here, we have list of nodes that satisfy initial latency requirement and the capacity requirement. Switch assignment is also done at this stage for all options.

4. Among those lists, calculate worst case path setup. Find farmost node pair. Calculate worst case path setup. We have switch assignments. Shortest paths NodeA to contA + nodeB to cont b + contb to cont a -> are considered worst case. Eliminate lists that do not meet worst case path setup requirement. Sort the rest.

5. During the eliminations if no lists meet requirements, add more nodes in prev. steps.

From now on, consider disaster resilience.

Sort the remaining lists acc. to maximum damage done based on the affected number of elements/connections (s-c shortest paths + controllers + c-c connections(connect all controllers to the closest controller to them with shortest path)) by a certain-sized disaster.

Up until now, we decide on the number of nodes, their locations, switch assignments.

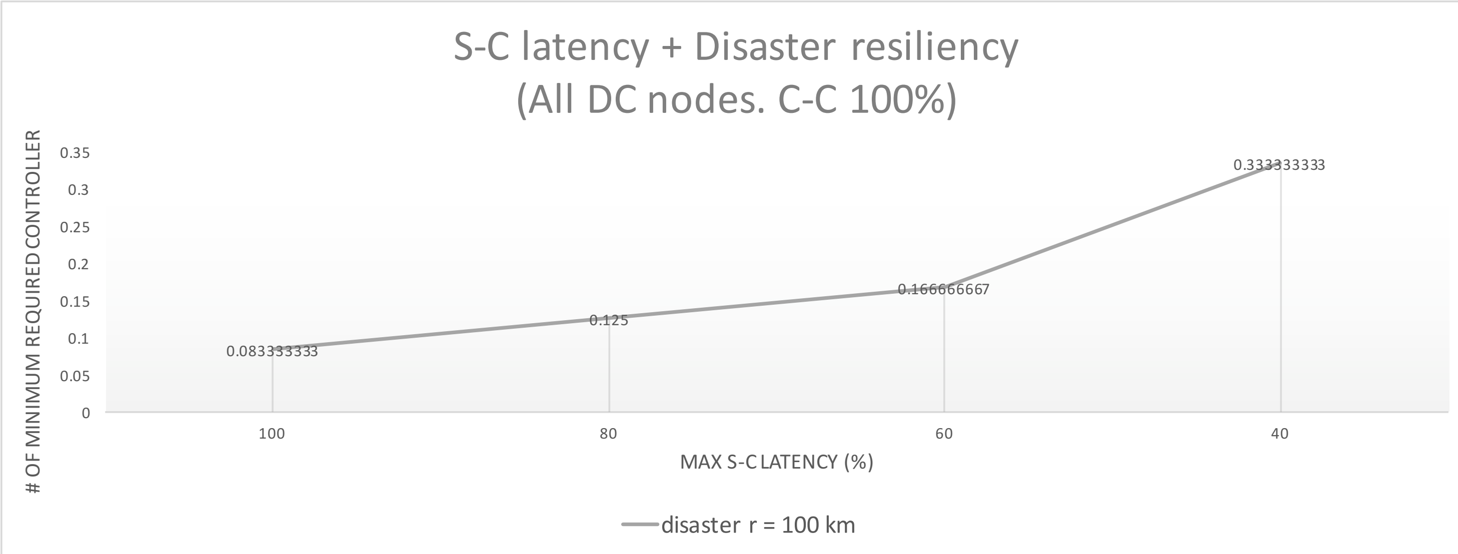
Deciding on VN links and mappings:

2-connected.

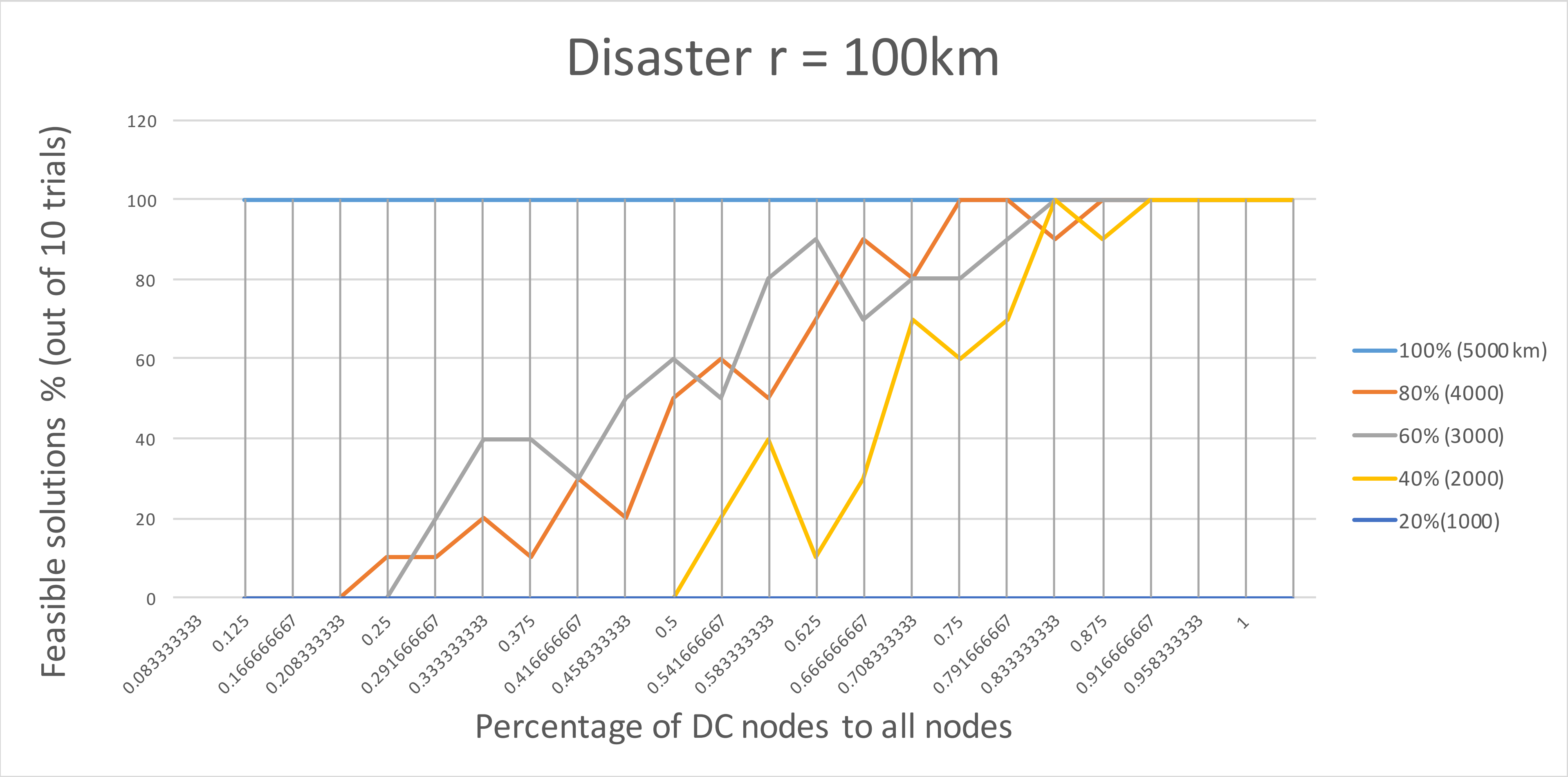
Ensure connectivity in case of any disaster sized r.

Control plane latency requirement for a full synchronization.

Minimize # of controllers by increasing controller number only when it is needed.
Not every distribution of dcs or amount gives feasible solutions.
Only consider the ones that do give.



	Max S-C delay %				
	100% (5000 km)	80% (4000)	60% (3000)	40% (2000)	20%(1000)
	100	80	60	40	20
# DC	2	3	4	8	unfeasible
DC percentage	0.0833	0.125	0.1666	0.3333	unfeasible



Disaster r = 100km
Feasible solutions % (out of 10 trials)
120
100
80
60
40
20
0
0.083333333
0.125
0.166666667
0.208333333
0.25
0.291666667
0.333333333
0.375
0.416666667
0.458333333
0.5
0.541666667
0.583333333
0.625
0.666666667
0.708333333
0.75
0.791666667
0.833333333
0.875
0.916666667
0.958333333
1
Percentage of DC nodes to all nodes
100% (5000 km)
80% (4000)
60% (3000)
40% (2000)
20%(1000)

Sensitivity analysis

- Effect of DC locations and amount.
- The effect of topology? # of nodes, average link lengths, and connectivity properties. If links are longer, more controllers needed when the delay tolerance is same.
- The effect delay tolerance?
- The effect of the size of the disaster?
- The effect of controller capacity?

The International Search and Rescue Advisory Group (INSARAG)

INSARAG is a global network of 80 countries and organizations under the United Nations umbrella.

Purpose: Strengthening the effectiveness and coordination of international urban search and rescue assistance

INSARAG

- INSARAG's international SAR protocol SAR process must be conducted by teams.
- Activity assignment and local decisions are brought by a team leader, while all the team activities are coordinated by an incident commander. A common SAR mission is conducted in four major steps:
- 1) the commander establishes the search area (a smaller search area minimize the problems of communication among the rescuers),
- 2) establishing of a command post in the search area,
- 3) first responders are divided into scouts and rescuers,
- 4) scout teams **report** their findings to the command post and rescuers **gather** the information

Help from the Sky: Leveraging UAVs for Disaster Management (1)

Leveraging the latest advances in wireless sensor network (WSN) and UAVs to enhance the ability of network-assisted **disaster prediction**, **assessment**, and **response**.

geophysical (earthquake, tsunami, volcano, landslide, and avalanche),
hydrological (flash-foods, debris flow, and floods),

climatological (extreme temperature, drought, and wild fire)

meteorological (tropical storm, hurricane, sandstorm, and heavy rain- fall)

Erdelj, Milan, Enrico Natalizio, Kaushik R. Chowdhury, and Ian F. Akyildiz. "Help from the Sky: Leveraging UAVs for Disaster Management." *IEEE Pervasive Computing* 16, no. 1 (2017): 24-32.

Help from the Sky: Leveraging UAVs for Disaster Management (2)

The major problem is the **lack of communication** and **situational awareness** during a disaster, forcing first responder teams to improvise and thus degrading the efficiency of the rescue mission.

First 72 hours, after the disaster hit are the most critical, which means that Search and Rescue (SAR) operations must be conducted quickly and efficiently.

Help from the Sky: Leveraging UAVs for Disaster Management (3)

Energy-effectiveness tradeoffs. Currently available off-the-shelf UAVs can remain airborne for approximately 15–20 minutes at a time. Thus, their mission must be highly optimized.

Dynamic topologies. Theoretical or a priori placement optimizations done centrally might not translate to the same exact locations in the corresponding 3D airspace. Unpredictable air drafts, inaccuracies in the 3D channel mod- els, and on- eld changing conditions can require sudden and unanticipated changes in UAV localization. Protocols that rely on next-hop forwarding, link- layer retransmissions, and error con- trol, among other approaches, must adjust to these situations in real time.

Multi-objective downtimes. Given the en- ergy demands, UAVs engaged in SAR functions require multiple rounds of re- charging. Each such downtime recalls the UAV to the nearest charging center, which raises interesting questions regard- ing whether the same network can be maintained (by introducing redundancy) or the entire topology must be proactively changed (at the cost of performance).

Various types of drones.

Drone type	Pros	Cons	Application	Price range (US$)
Fixed-wing	Large area coverage	Inconvenient launch and landing Price	Surveying an area, structural inspection	$20,000–$150,000
Rotary-wing (helicopter)	Hover flight Increased payload	Price	Aerial inspection, supply delivery	$20,000–$150, 000
Rotary-wing (multicopter)	Availability (price) Hover flight	Low payload Short flight duration	Aerial inspection, filmography, photography	$3,000–$50,000

20-30 minutes airborne operation duration, 80 minutes charging duration.

A fixed or mobile first-response UAV station

- automatic battery replacement

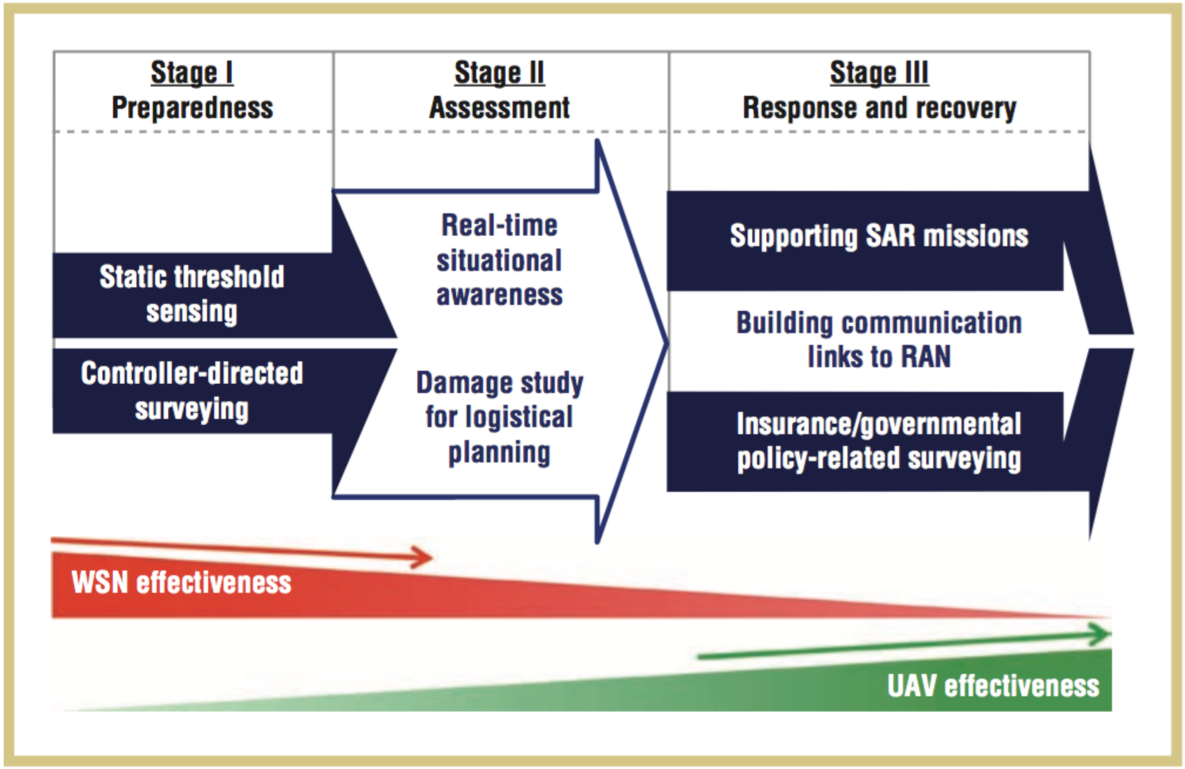


Figure 1. Disaster stages and UAV-assisted operations. As the disaster stages progress, static wireless sensor network (WSN) deployments become less effective.

Single optimized but static network for all three stages is no longer sustainable; rather, the network must continuously evolve in topology and capability.

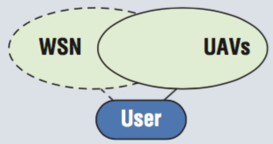
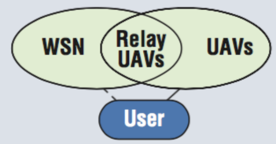
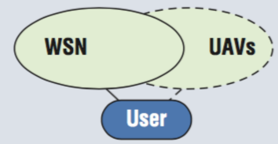
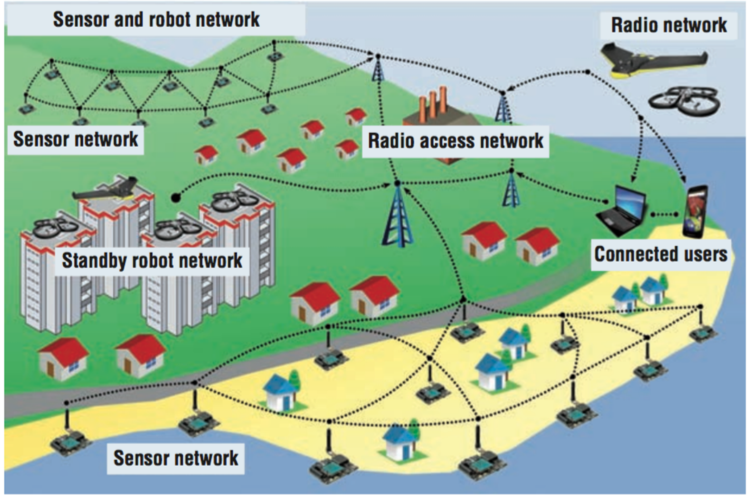
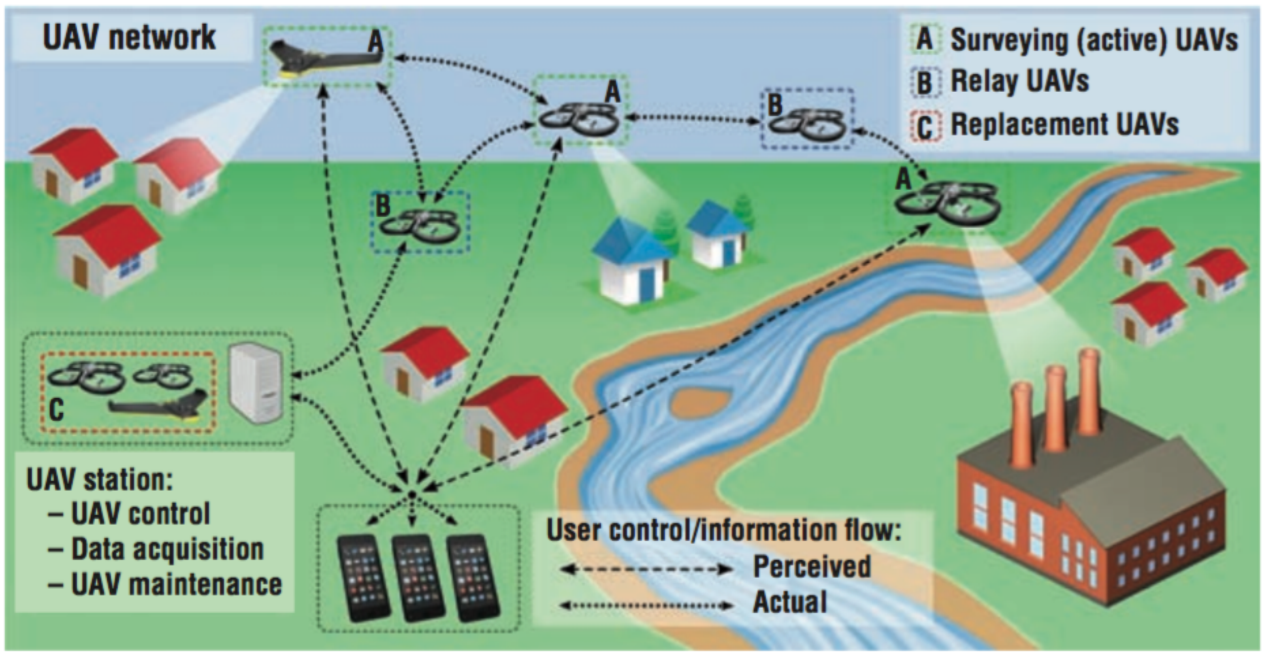
Disaster stages	Disaster type and impact on technology					
	Type A: Geophysical or Hydrological		Type B: Climatological, hydrological, or human-induced		Type C: Meteorological	
	WSN not operational UAVs fully operational  		WSN partially operational UAVs fully operational  		WSN fully operational UAVs partially operational  	
Preparedness: Monitoring and surveying Early Warning Systems (EWS)	WSN with limited UAV roles					
	Different types of wireless sensors are statically deployed in the potential disaster area An occurrence of a disaster triggers WSN reporting with optional UAV support					
Assessment: Situational awareness Damage assessment Structural inspection	No WSN	UAV	Partial WSN	UAV	WSN	No UAV
	Damage assessment and structural inspection is being done by UAVs		Damage assessment is done by UAVs, backed up by the operational part of WSN		WSN information fusion for situational awareness	
Response and recovery: Rescue missions Supply delivery Communication system	No WSN	UAV	Partial WSN	UAV	WSN	No UAV
	Sensing, monitoring, SAR, and communication restoration is being done by UAVs		UAVs restore the broken connectivity and SAR operations using a combination of WSN and UAVs		Integration of aerial surveys and ground observations for efficient decision support systems	

Figure 2. Disaster types, their impact on technology, and system classification.

Since the WSN is still operational and able to route packets to the remote sink, the mobile units perform more of the exploratory tasks but then leverage the long-lived WSN as the data-forwarding backhaul (buffer and distribute packets along the end-to-end chain).




UAV network
A Surveying (active) UAVs
B Relay UAVs
C Replacement UAVs
A
A
B
A
B
C
UAV station:
– UAV control
– Data acquisition
– UAV maintenance
User control/information flow:
Perceived
Actual

Challenges

Supporting in-network data fusion. The video/images collected by the UAVs present an overview of the situation. Affected humans might media via the UAV relay network also useful.

Addressing handover issues. Unlike handoff in cellular systems, the hand- over among UAVs—such as during recharging events—is considerably more involved.
A handover involves replicating the exact operational state in the incoming UAV—including forwarding tables, packets in the buffer, and data fusion rules—which escalates the messaging between the UAVs.

Systems and methods for a mobile uav-based emergency communication scanner **(16 Patent by Nokia)**

Motivation

In prev. works, UAVs are considered as a network element and to replace the damaged infrastructures. This requires a UAV to hover over a location continuously.

Benefit: real-time communication

UAV would only act as a "Post-man" where in the UAVs would collect the signals (eg., SMS), go to a nearby tower and deliver the signals or vice-versa

Benefits: cost-effective

Systems and methods for a mobile uav-based emergency communication scanner **(16 Patent by Nokia)**

UAV based emergency communication scanner is comprised of an unmanned aerial vehicle (UAV), deployed sensor resources, mapping application and a big-data center.

- Data is collected in distributed manner
- Uses localized collection of data by UAV's to avoid high-burst communication scenarios
- In absence of UAV's, system can provide offline data collection capabilities to minimize stress on the network.
- UAV's resolve data collection problem when conventional communication channels are not available
- Able to collect visual data from data collection areas.
- Longer battery life

Creating Network Resilience Against Disasters Using Service Level Agreements

Network has different demands and requirements when it is normal than when it is in a disaster or emergency status.

if resources are limited following the disaster, how do we select which services to reroute?

On the provisioning side, the SLAs will provide the required system response time, availability and survivability of a service. On the remediation side, the SLA can provide the priority of a service to restore and reroute.

Gardner, M. T., Cheng, Y., May, R., Beard, C., Sterbenz, J., & Medhi, D. (2016, March). Creating network resilience against disasters using service level agreements. In *Design of Reliable Communication Networks (DRCN), 2016 12th International Conference on the* (pp. 62-70). IEEE.

Creating Network Resilience Against Disasters Using Service Level Agreements

1) Collect *Normal* demands/SLAs
2) Collect *Emergency* demands/SLAs
3) Select a resilient topology (not the subject of this work)
4) Assign capacity using a multi-situational capacity planning approach
5) Create a prioritized restoration approach for an emergency mode

Gardner, M. T., Cheng, Y., May, R., Beard, C., Sterbenz, J., & Medhi, D. (2016, March). Creating network resilience against disasters using service level agreements. In *Design of Reliable Communication Networks (DRCN), 2016 12th International Conference on the* (pp. 62-70). IEEE.

Resilient SLA Configuration

Response Time is the maximum end-to-end response time

Availability is used to specify the service availability. I

Survivability is specified for the emergency demands d that are required during times of network challenge.

If a service with survivability is specified but is not of high availability, it may not be restored during a normal component failure but would be rerouted with priority during network challenges.

Reroute the emergency operating mode services first, and then reroute the remaining services using shortest path routing.

Gardner, M. T., Cheng, Y., May, R., Beard, C., Sterbenz, J., & Medhi, D. (2016, March). Creating network resilience against disasters using service level agreements. In *Design of Reliable Communication Networks (DRCN), 2016 12th International Conference on the* (pp. 62-70). IEEE.