Beyond Best Effort: Routing with Requirements

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Resume

Brad Smith received the master's and Ph.D. degrees in Computer Science from the University of California Santa Cruz in 1997 and 2003, respectively. He has held an Adjunct Faculty position in the Computer Science & Engineering Department of the Baskin School of Engineering since 2006, and has served in leadership positions in the Information Technology Division at UCSC including Director of Computing for the School of Engineering, Director of Core Technologies, and Vice Chancellor Information Technology from 1990 to 2016.

Research Interests & Current Projects

Brad is working in the areas of policy-based routing and the application of these technologies to the improvement of the security and robustness of Internet-based systems. He was a part of the Computer Communication Research Group (CCRG) led by Prof JJ Garcia-Luna. Working with Paul Tatarsky (co-author) he developed the technology presented here with a National Science Foundation Small Business Innovative Research (SBIR) grant. He is looking to build a team to develop a production-grade implementation and look at commercialization opportunities. He is also working on developing open source implementations of state-of-the-art routing protocols that were developed in the CCRG.

The Need - Effective Resource Control

Control *who* can transmit *what traffic* to *whom* over *what parts of the network* and *how the traffic should be handled*

Routing with Requirements developed to solve this!

Problems with the original Internet

Proposed Solution
Routing with requirements

How get *best set of paths* & Benefits

Testbed & Summary

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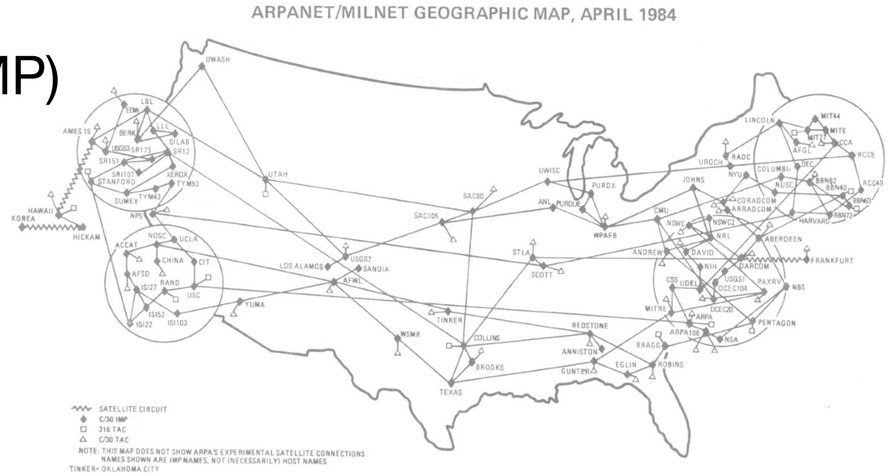
Current Internet - Features & Limitations

- Simple architecture
  - Single best path (generalized to be sbp *weight* w/ ECMP)
  - Universal <u>reachability</u>
  - Best effort delivery - all packets handled the same
  - Hugely successful - “*works over anything!*”



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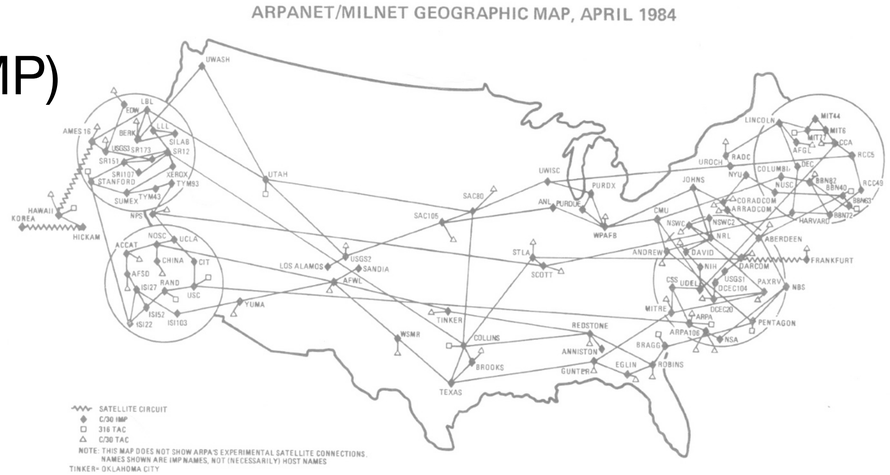

- Challenged by new requirements
  - Performance & policy control **vs** universal reachability, best effort delivery
  - High reliability **vs** low level network abstraction (VLANs/queues/priorities)
  - Ease of configuration **vs** complex technology (firewalls/network segmentation/etc)
  - Efficient use of resources **vs** single path/ECMP routing (30-40% link utilization)

Summary

Properties	Problems
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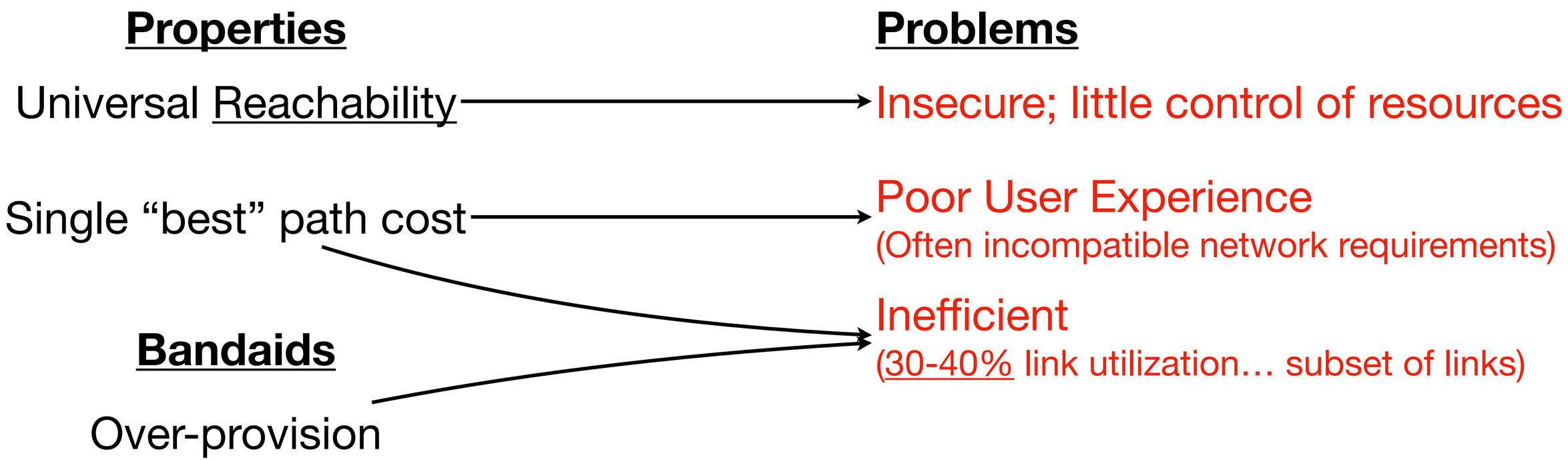
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Over-provision → Inefficient
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Add-on functions → Cost and complexity
(firewalls, policy routing, queuing disciplines)
("how" implement desired properties)

Attempts to Mitigate

- Current solutions:
  - In network (core) – *single-flow* (MPLS) or *single-traffic class* (SR) are inefficient and complex
  - On network (overlay) – add-ons (firewalls, segmentation, …) are *expensive*, *complex*, *fragile*
  - Virtualization – magnify resource utilization, *low level network abstraction*
  - Programmability (SDN) – magnify expertise/labor, *low level network abstraction*
- Problems
  - *Inefficient* (single-flow (MPLS)/traffic class (SR) forwarding state)
  - *Fragile* (semi-static core, and overlay functionality not aware of topology)
  - *Insecure* (universal reachability, complex and error-prone configuration)
  - *Expensive* (complex overlay functions, expertise and labor intensive)
  - *Complex* network configuration (low level network abstraction)

Comparing solutions…

- Four Issues
  - *Single weight* vs *best set of weights*

	Path Weights Computed?
Original Routing	**Single Best Weight** (for a single traffic class)
MPLS	**Single Best Weight** (per configured traffic class)
SR	**Single Best Weight** (per configured traffic class)
RwR	**Best Set of Weights** (for ***all traffic classes***!!)

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  - *Single weight* vs *best set of weights*
  - *Fate sharing* vs *Distributed state*

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MPLS	**Single Best Weight** (per configured traffic class)	**No** (path state in ***each hop***)
SR	**Single Best Weight** (per configured traffic class)	**Yes** (path state in ***packets***)
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  - *P2MP* vs *P2P* flow state)

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RwR	**Best Set of Weights** (for ***all traffic classes***!!)	**Yes** (path state in ***router***)	**Yes**	**Yes** (for ***all*** traffic classes!!)	**Scalable, robust, efficient, *all possible traffic classes!!***

Comparing solutions…

- Four Issues
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- SR – *person in the loop*
  - Per-traffic class QoS and TE requirements
  - Heavily engineered networks; advanced skills
- RwR – *one-time config of needed parameters*
  - ***Network autonomically satisfies requirements and minimizes contestion***

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Future Internet target use cases

- Health-care
- Transportation
- Manufacturing
- Agriculture
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With “hard” requirements

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Network engineers do not know how they’re going to implement them!

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Ordered, ***performance requirements*** (delay, bandwidth, etc.)

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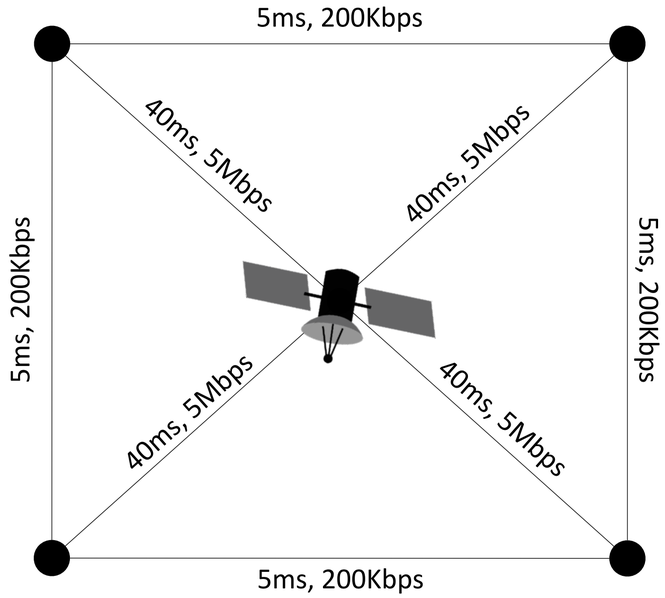
Categorical requirements with Boolean expressions

Quality of Service - video and VoIP traffic

- ***Link metrics***: delay, bandwidth



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- ***Link metrics***: delay, bandwidth
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  - VoIP: ≤ `50ms` delay, ≥ `100Kbps` bandwidth
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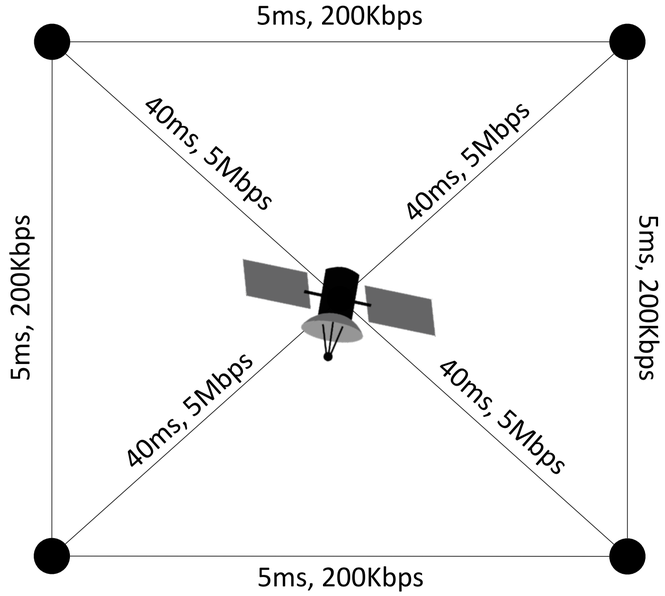

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  - VoIP: ≤ `50ms` delay, ≥ `100Kbps` bandwidth
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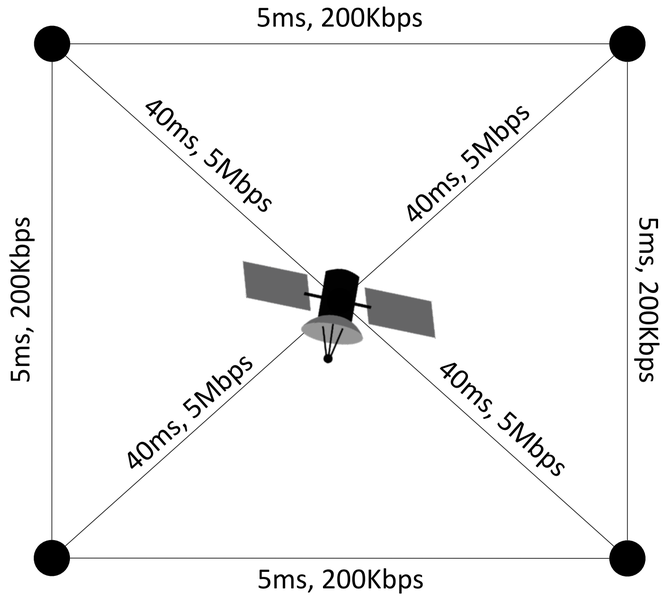
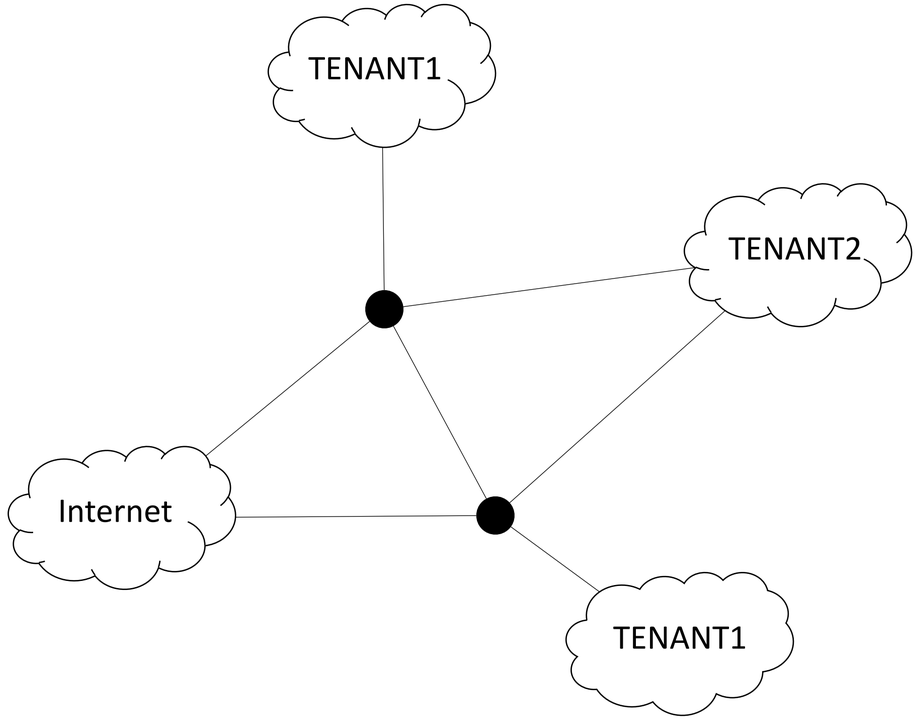
- *Traffic is forwarded over path that satisfies flow performance constraints; if more than one, use least congested*



Multitenant

- ***Flow variables***: `TENANT1`, `TENANT2`



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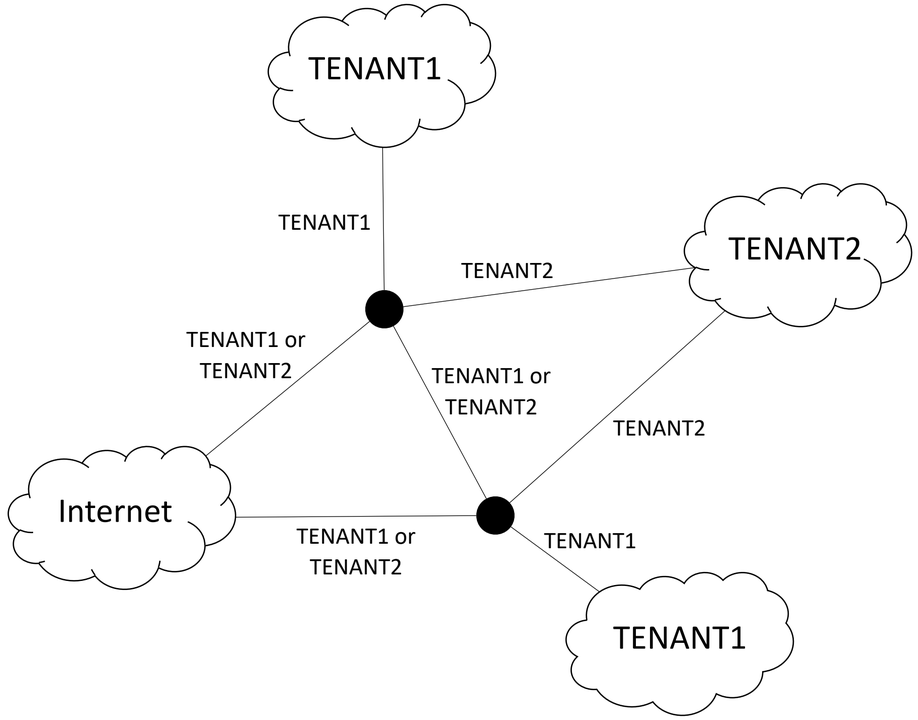

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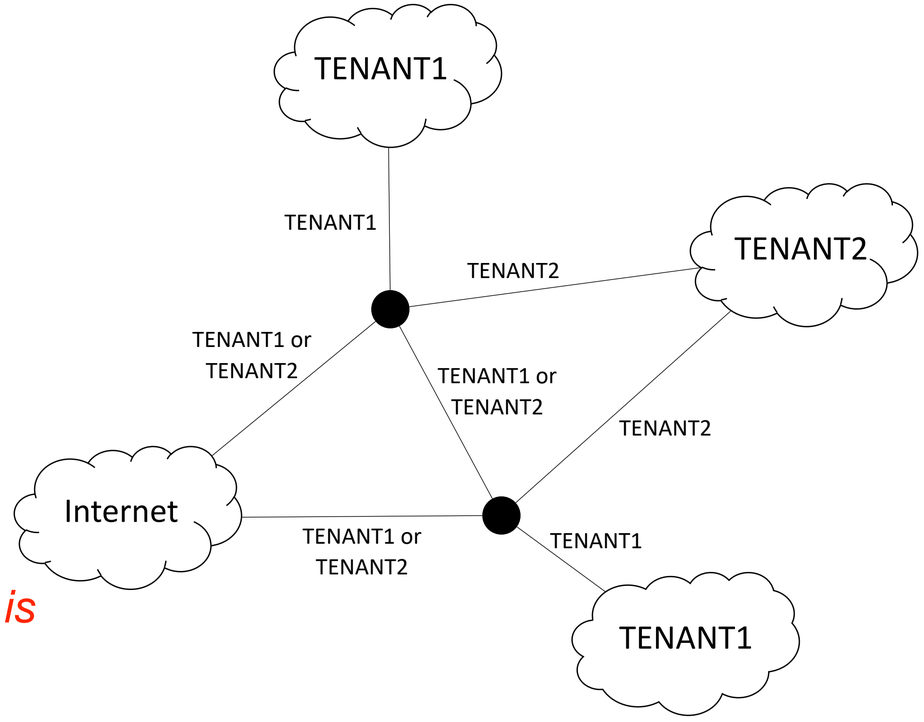

Three Tier Web Architecture using Zero Trust

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  - Flow data types: `WEB_D`, `APP_D`, `DB_D`
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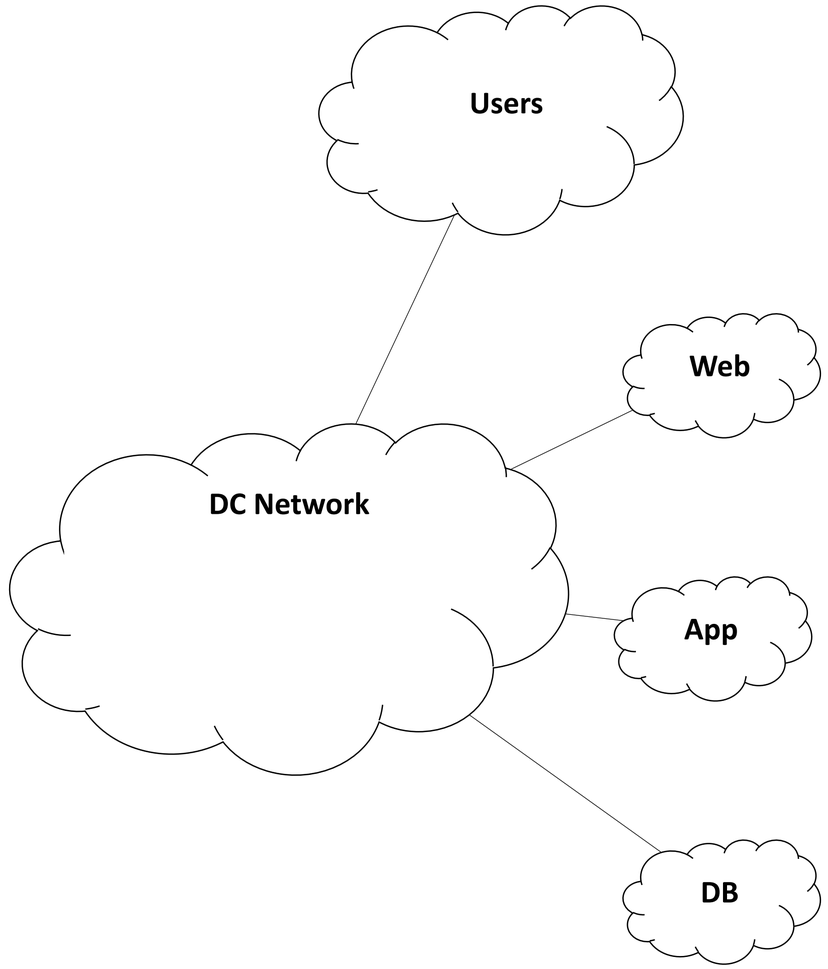

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- ***Global requirements***

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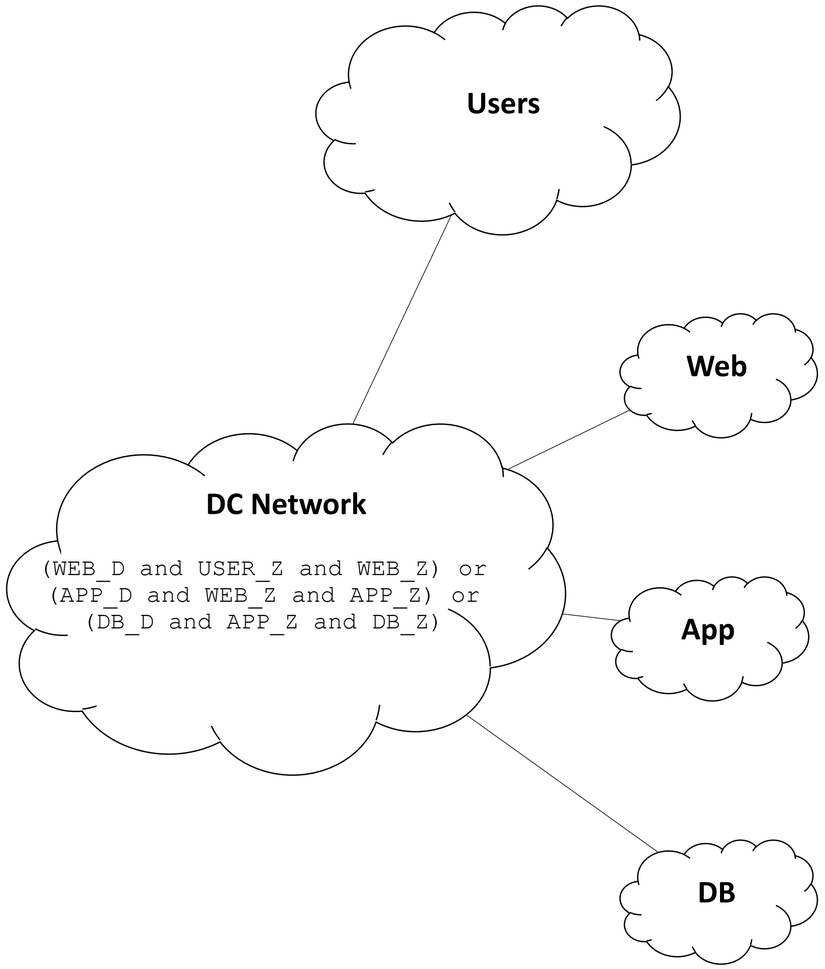

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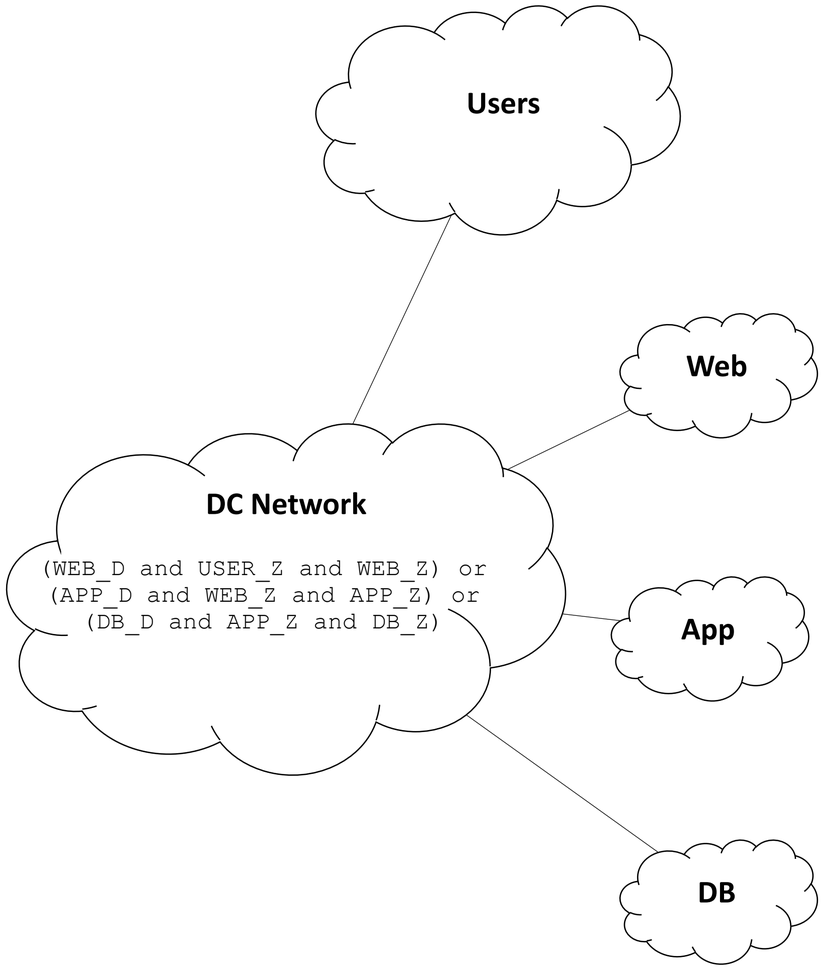
- *Traffic at each layer is isolated.*



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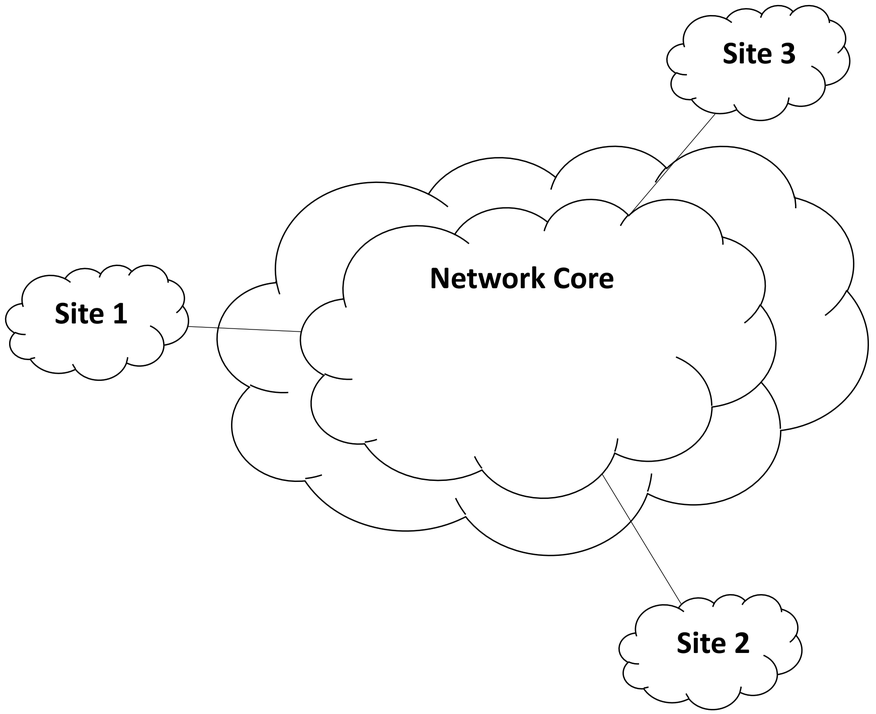
  - ***Controller managed variables***
    - Date/time, interface info (speed, media type, drop statistics, encryption, etc.), …
  - ***Programmatically controlled variables***
    - External systems control variables using API
      - Examples: threat status, user/host information from “network access control” (NAC) systems
    - Prototype implemented a REST interface

Time of Day Backups - *controller* variables

- ***Flow variable***
  - `BACKUP`



Time of Day Backups - *controller* variables

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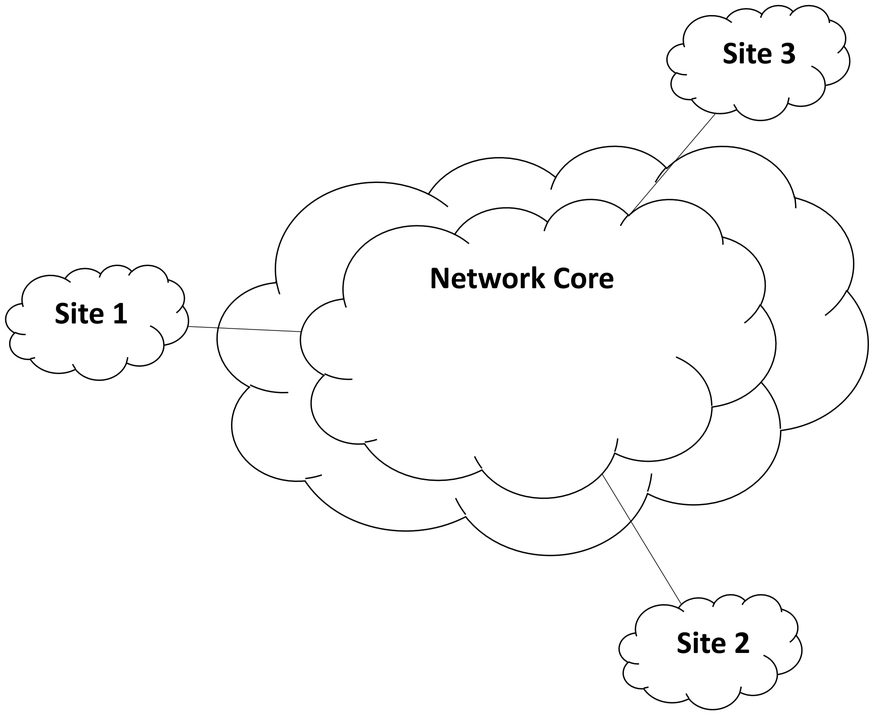
  - `NIGHT` - *value set by controller!*



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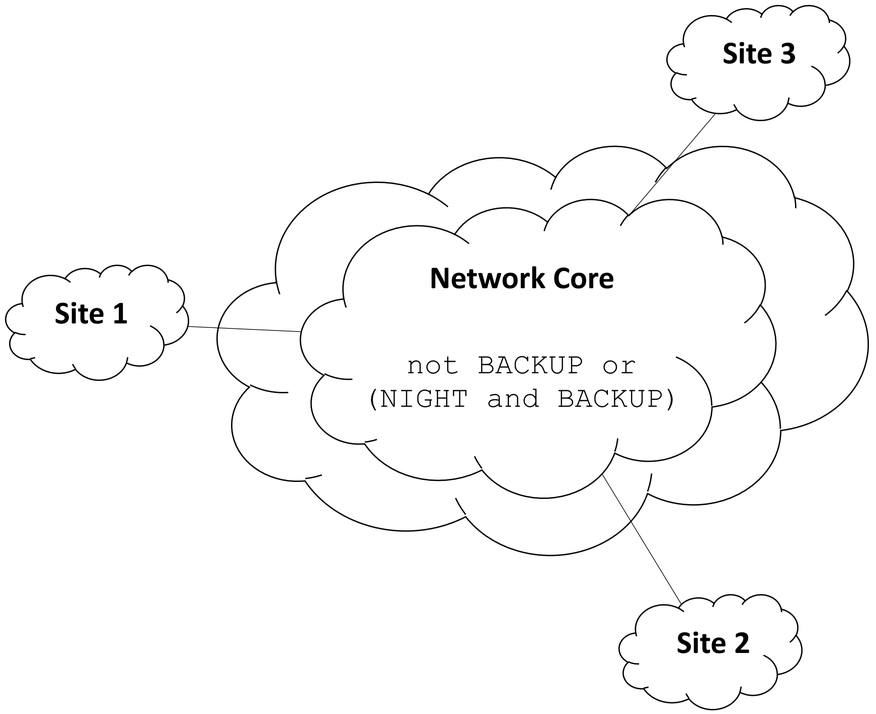

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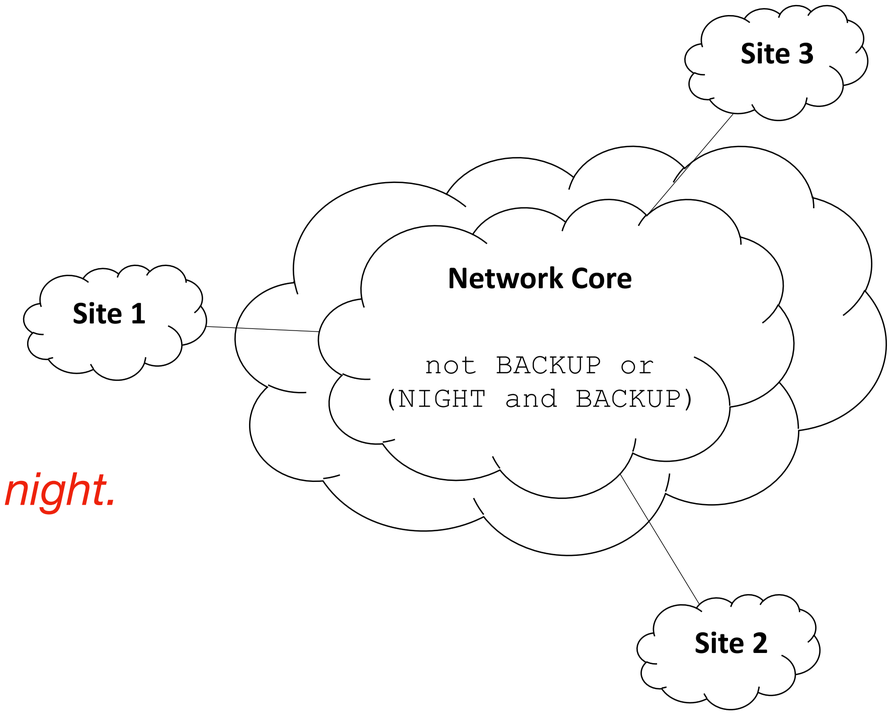
- *Backup traffic only allowed on network core at night.*



Multi-Layer Security

- ***Flow variables***
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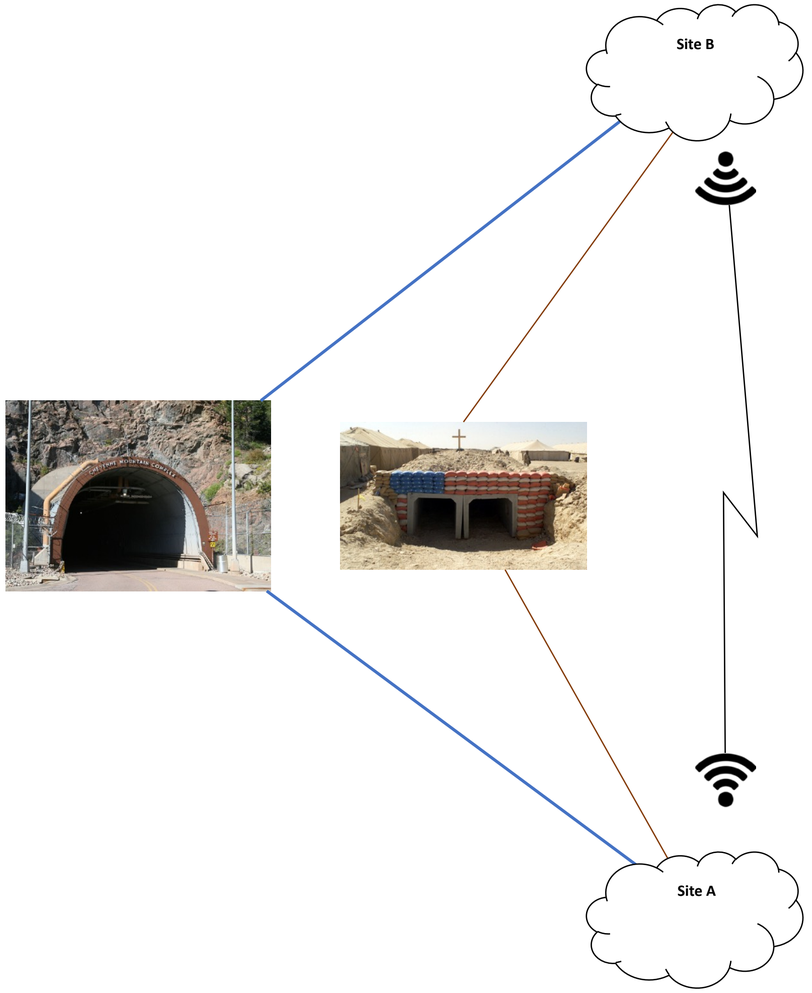

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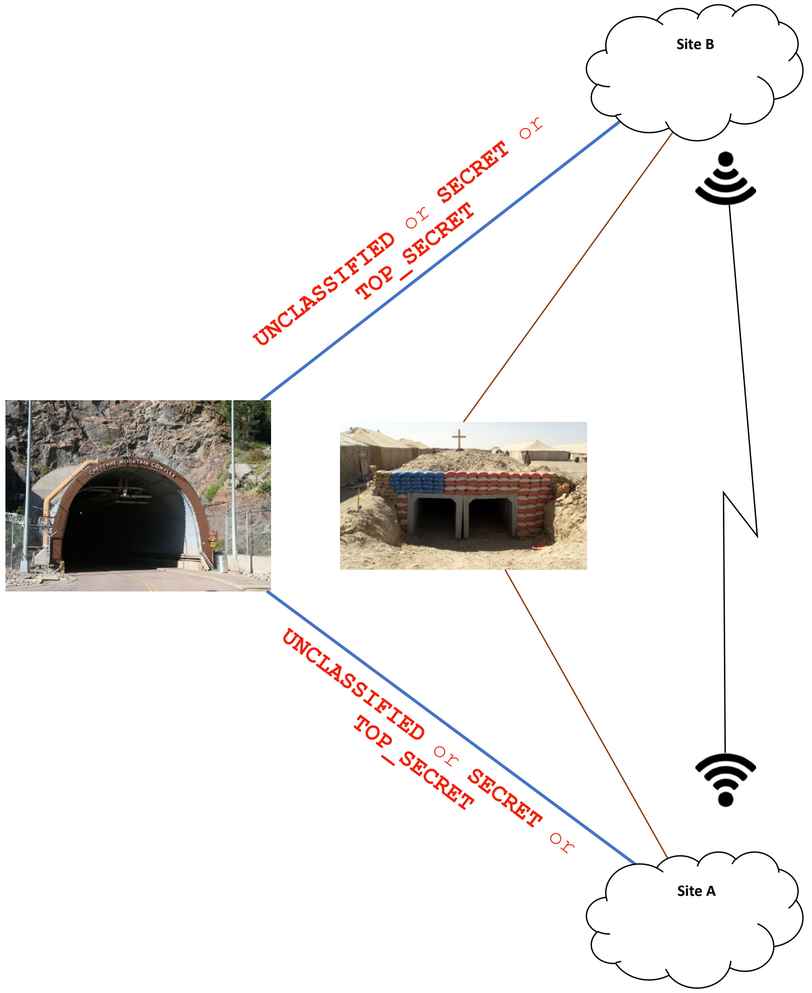

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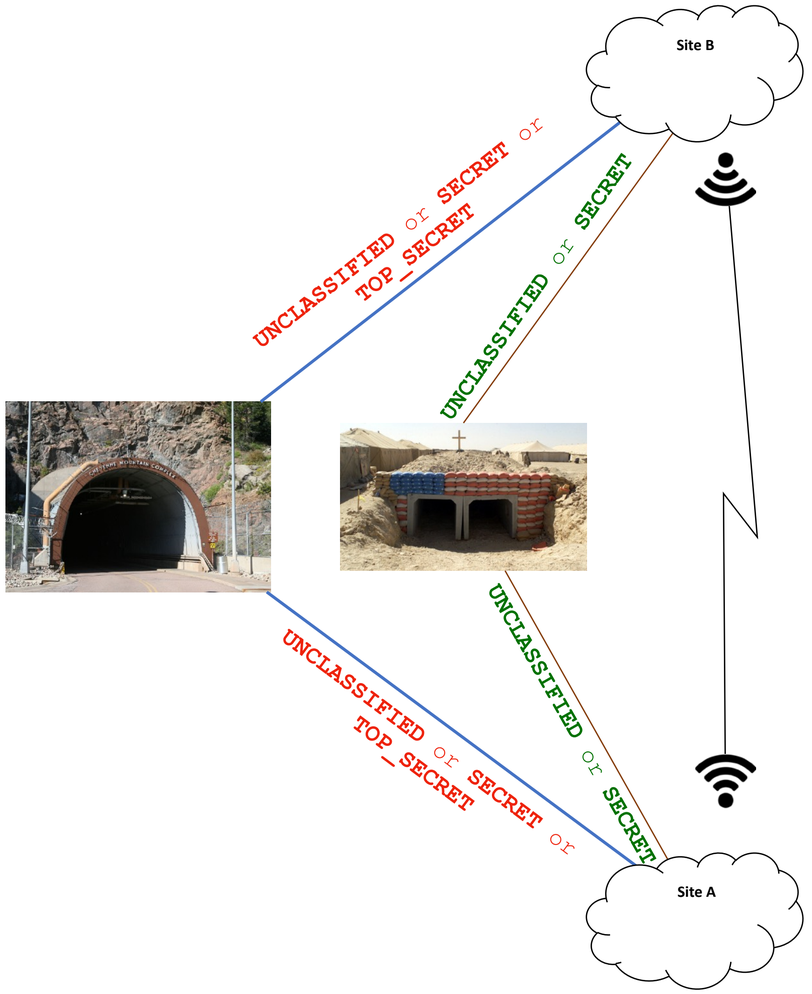

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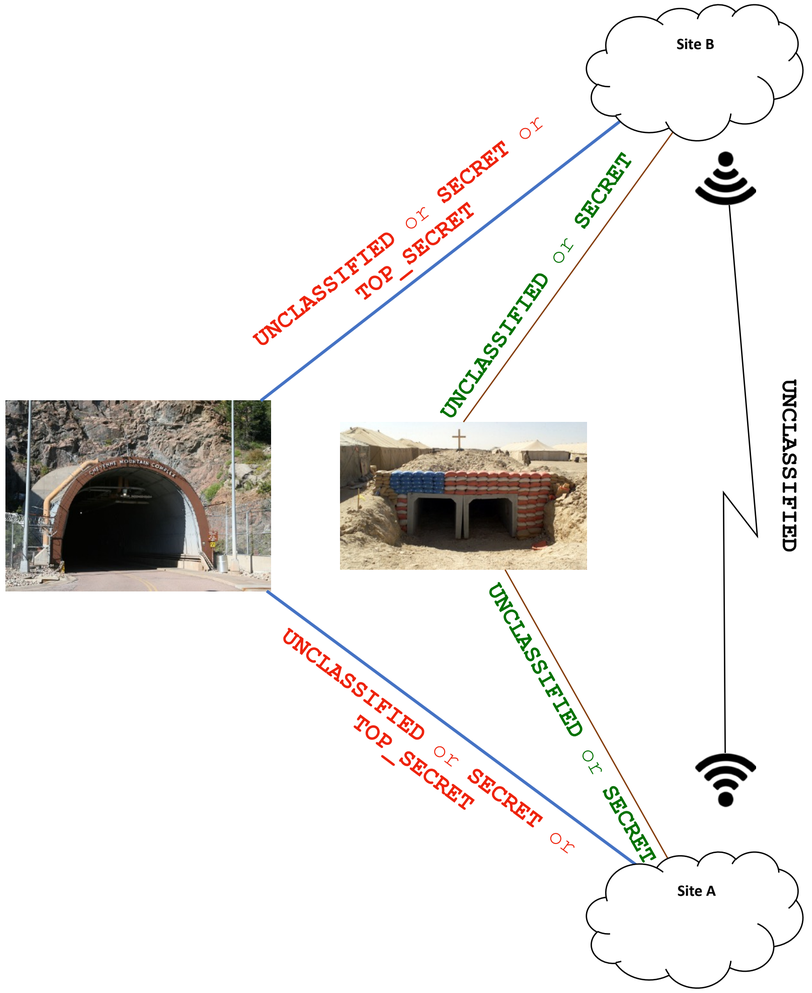

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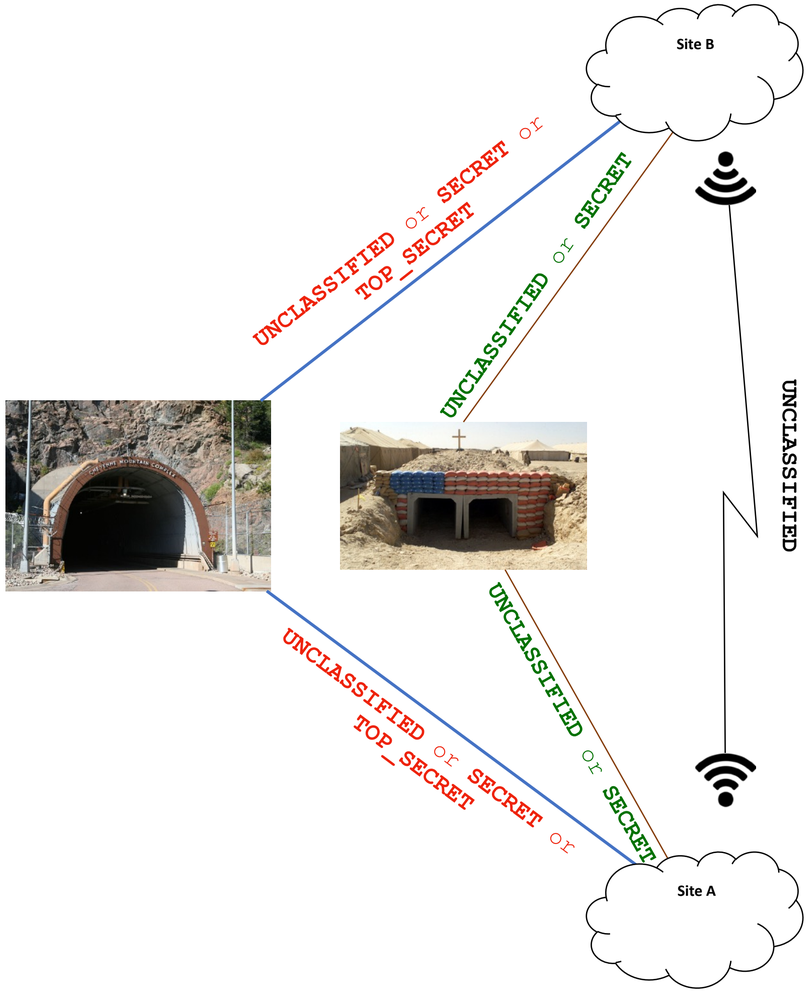
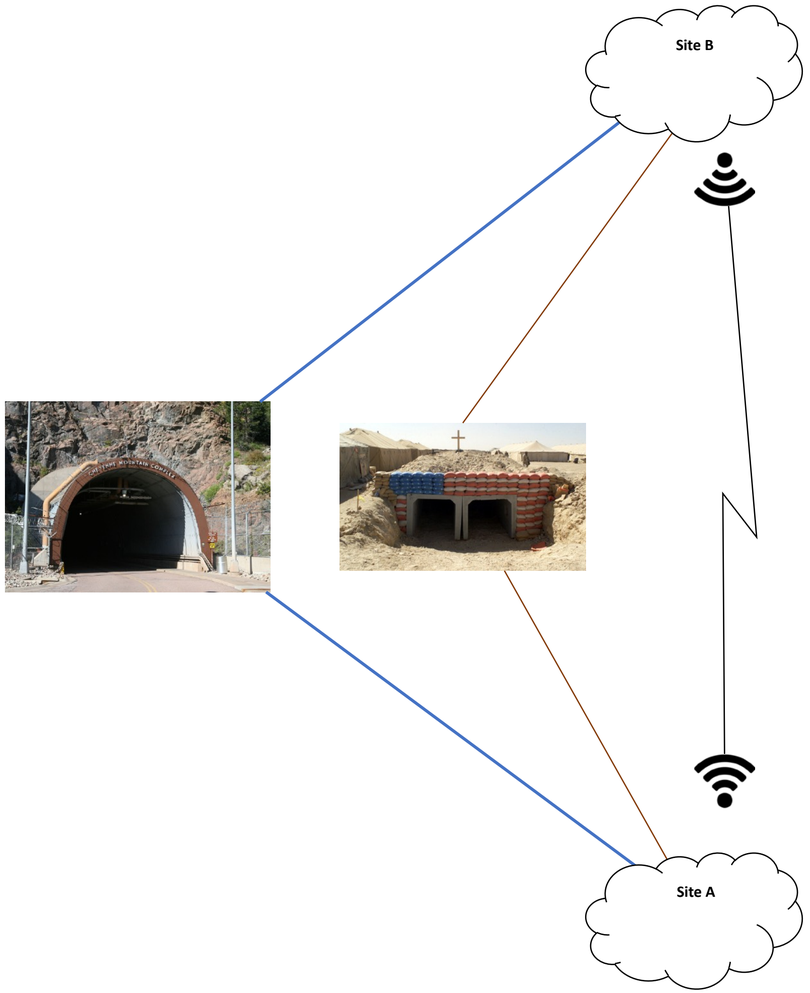
  - SECURED: `UNCLASSIFIED or SECRET`
  - UNSECURED: `UNCLASSIFIED`
- *Traffic is routed over appropriately secure paths.*



DEFCON/MLS - *programmatic* variables

- ***Flow variables***
  - **TS**
  - **SEC**
  - **UNC**



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  - **DEF1**
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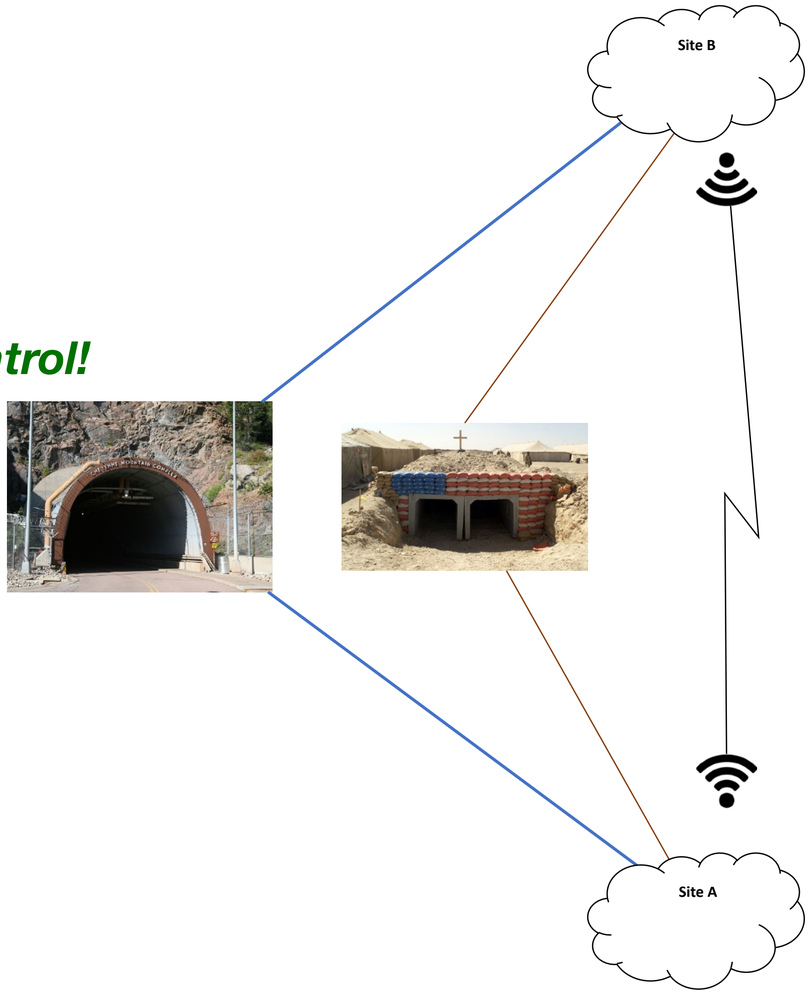

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  - **DEF1**
  - **DEF3**
- ***Link requirements***
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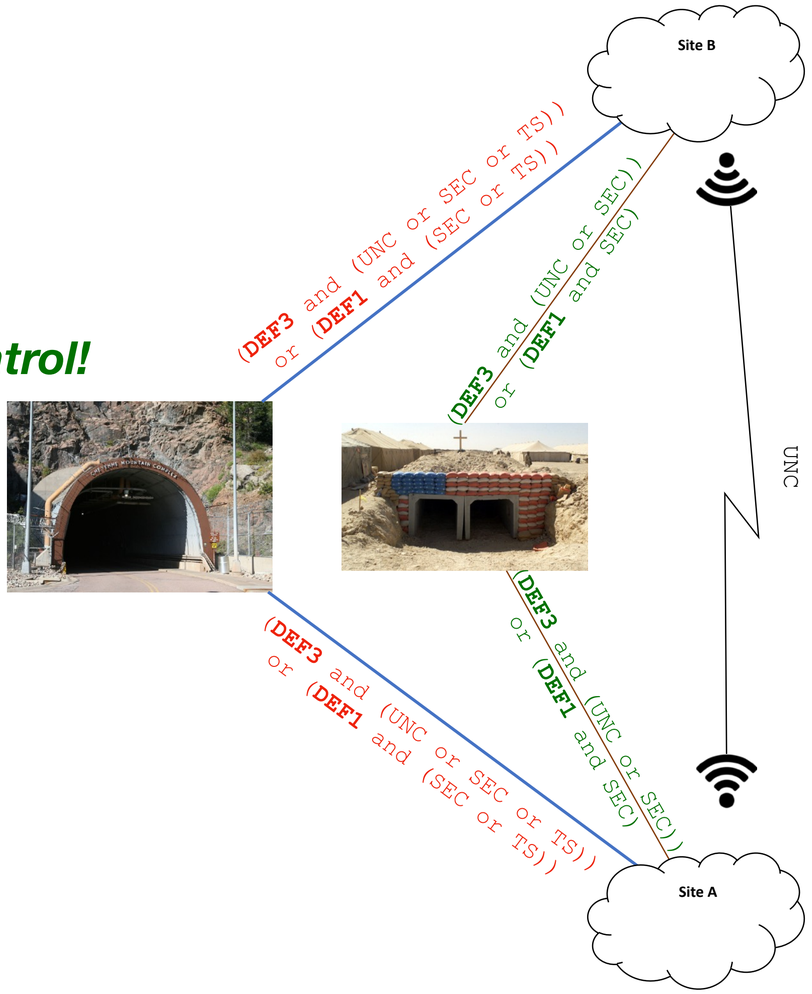
  - (**DEF3** and (UNC or SEC)) or (**DEF1** and SEC)
  - **UNC**



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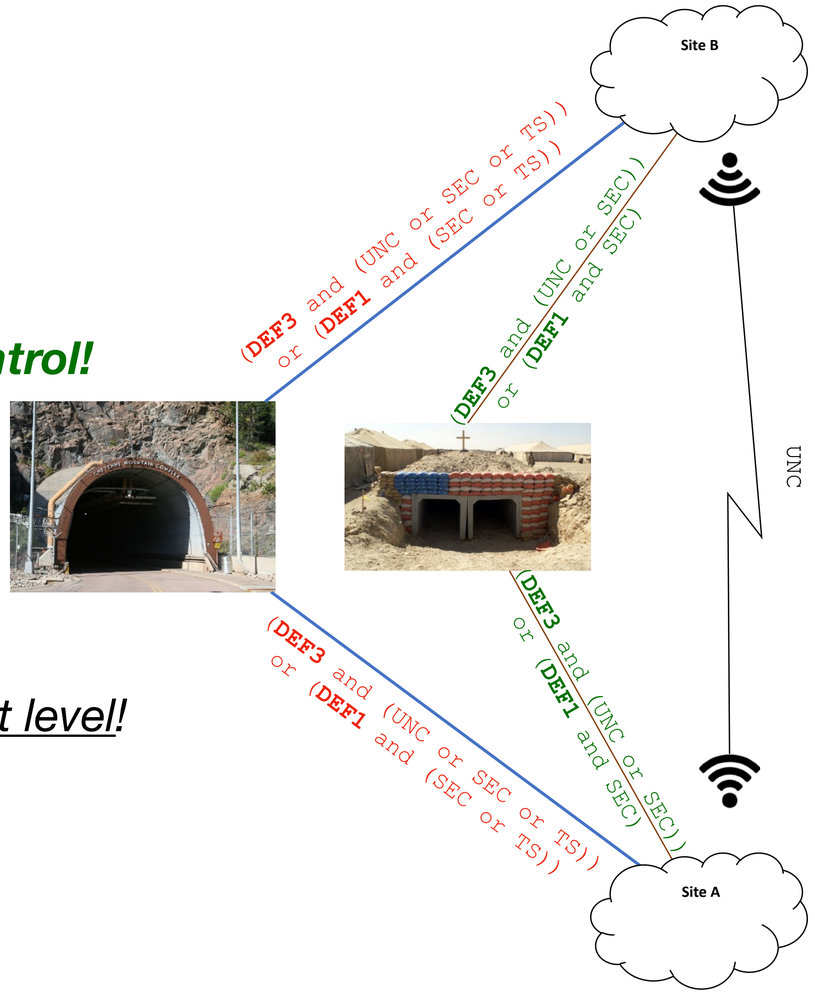
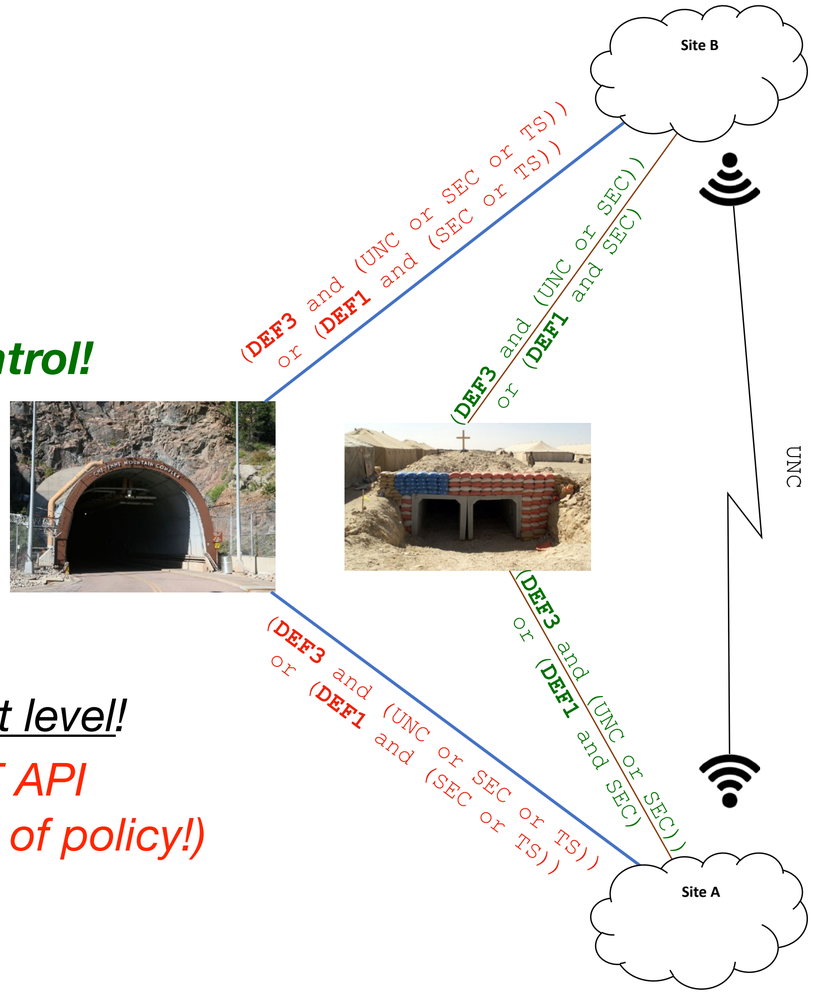
  - (**DEF3** and (UNC or SEC)) or (**DEF1** and SEC)
  - **UNC**
- *Traffic is routed over paths with security appropriate to threat level!*



DEFCON/MLS - *programmatic* variables

- ***Flow variables***
  - **TS**
  - **SEC**
  - **UNC**
- ***Environmental requirements*** - ***remote programmatic control!***
  - **DEF1**
  - **DEF3**
- ***Link requirements***
  - (**DEF3** and (UNC or SEC or TS)) or (**DEF1** and (SEC or TS))
  - (**DEF3** and (UNC or SEC)) or (**DEF1** and SEC)
  - **UNC**
- *Traffic is routed over paths with security appropriate to threat level!*
- *In prototype we implement environment variables with REST API (programmatic control of DEFCON enables external steering of policy!)*



Problems with the original Internet

Proposed Solution
Routing with requirements

How get “best set of paths” & Benefits

Testbed & Summary

A single weight is very limiting

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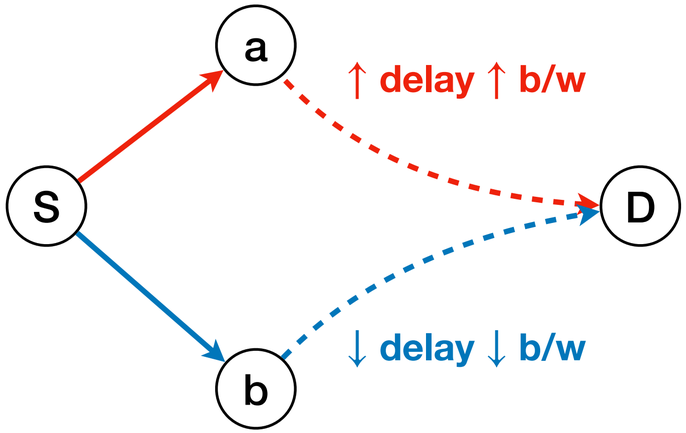

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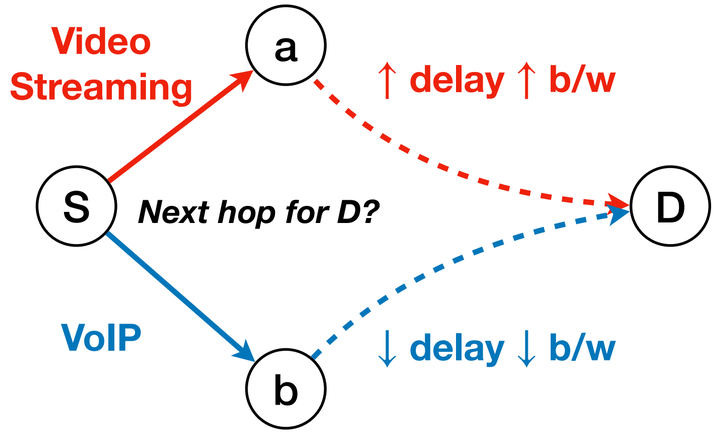

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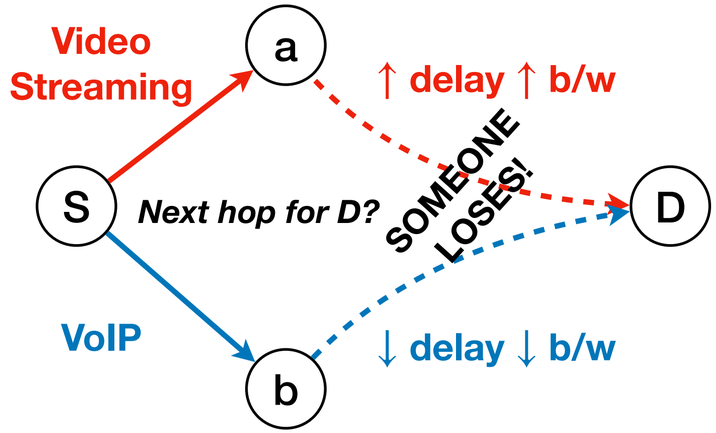

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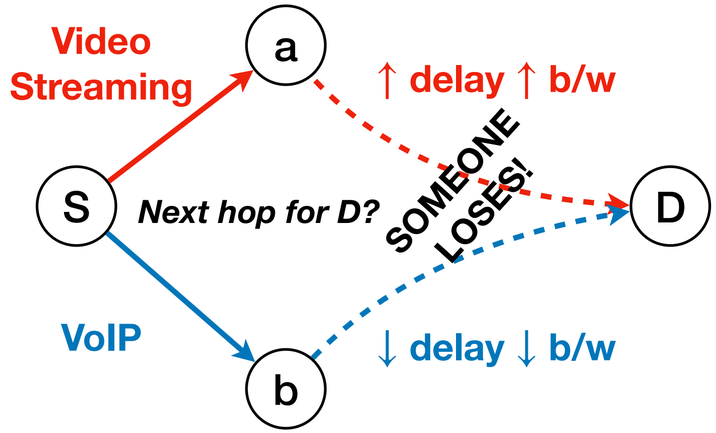

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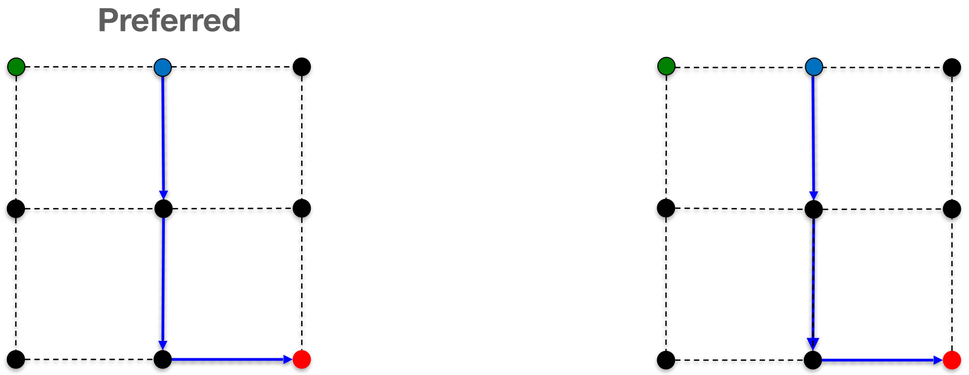

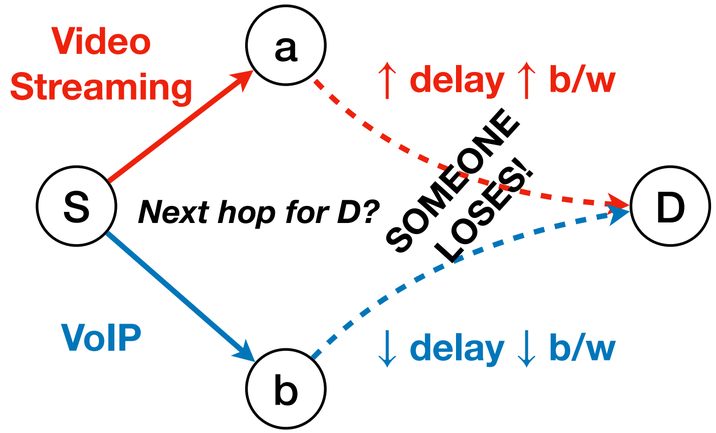

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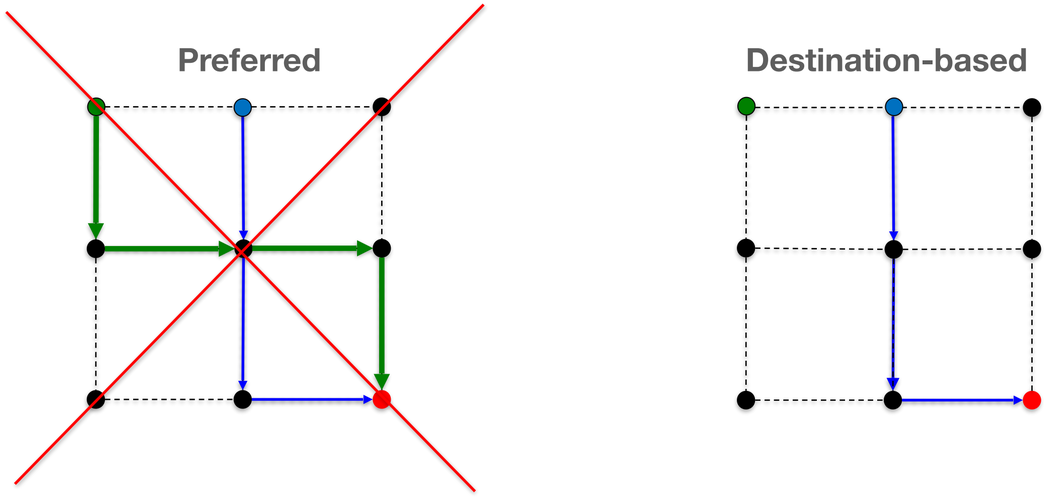

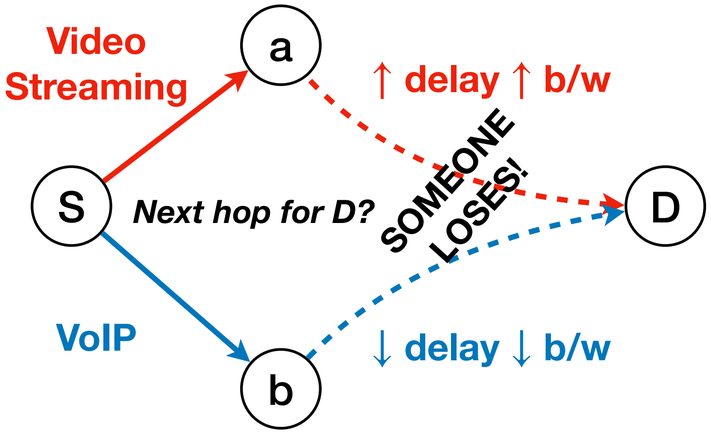

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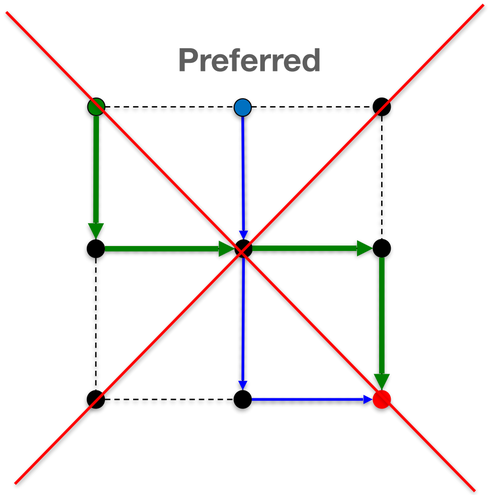
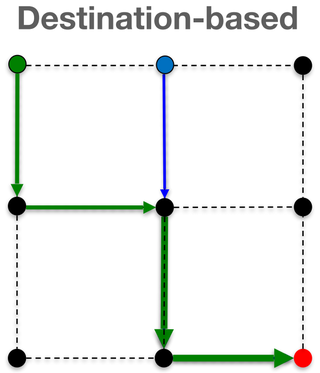
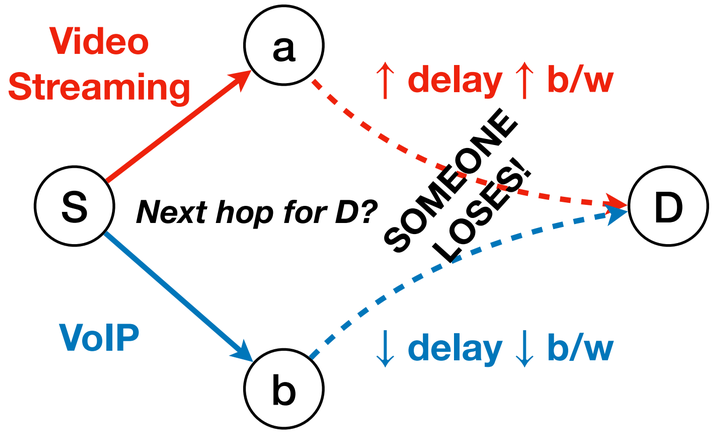
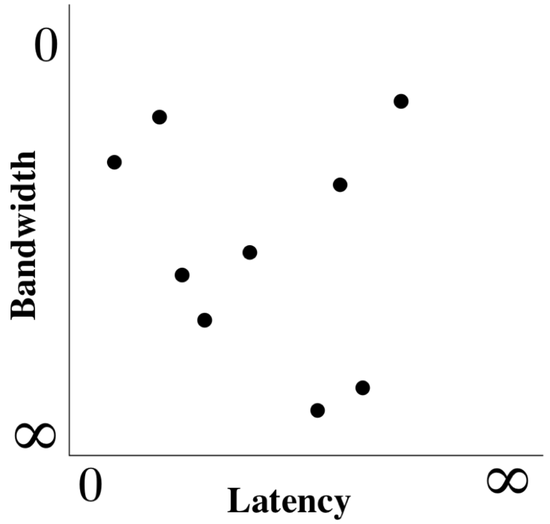






Paths to the same destination must overlap once they intersect.

Ordered requirements - QoS b/w and latency



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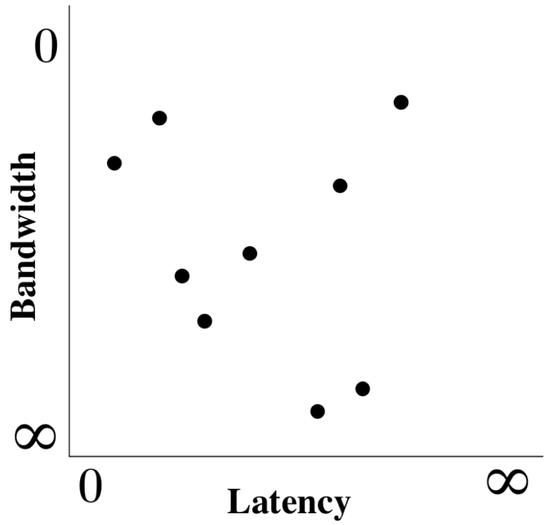

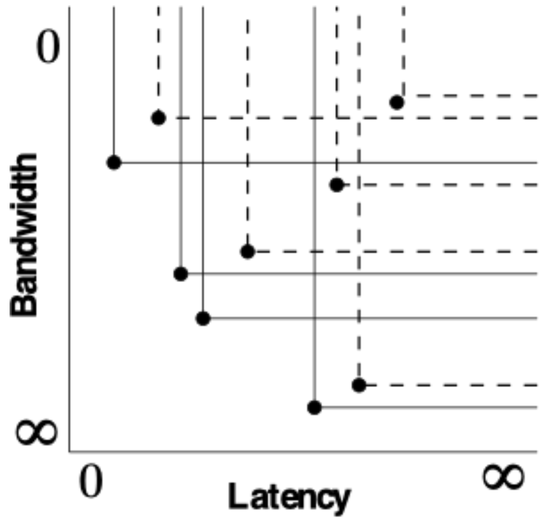

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- Some paths are “better” than others

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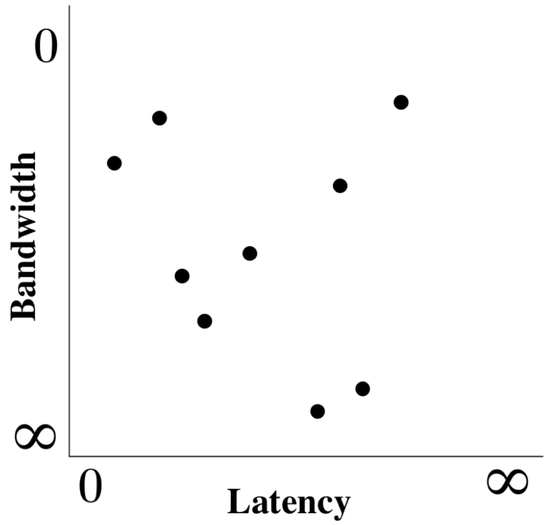

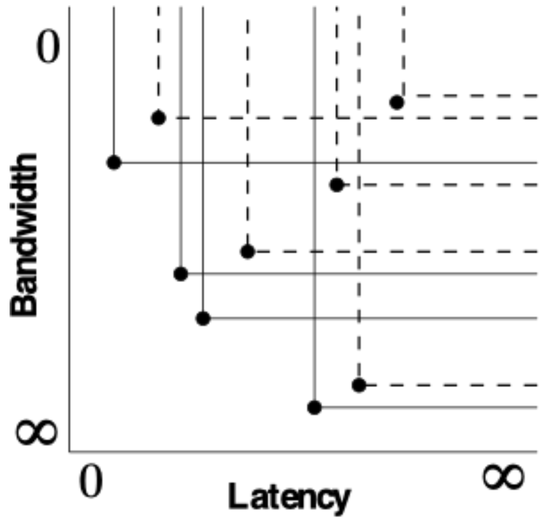

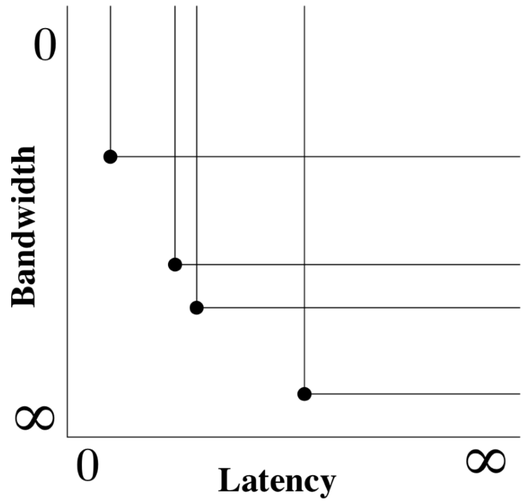

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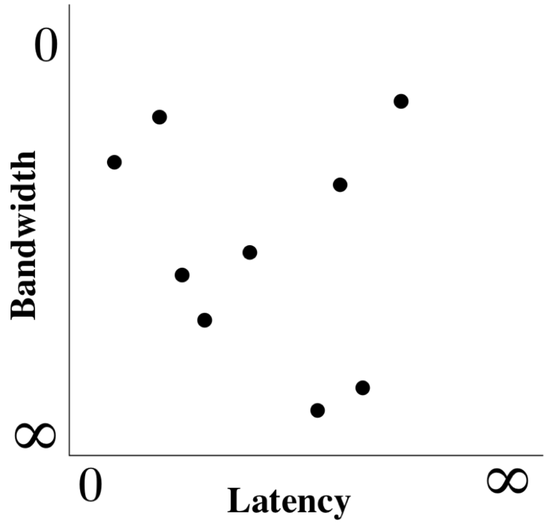

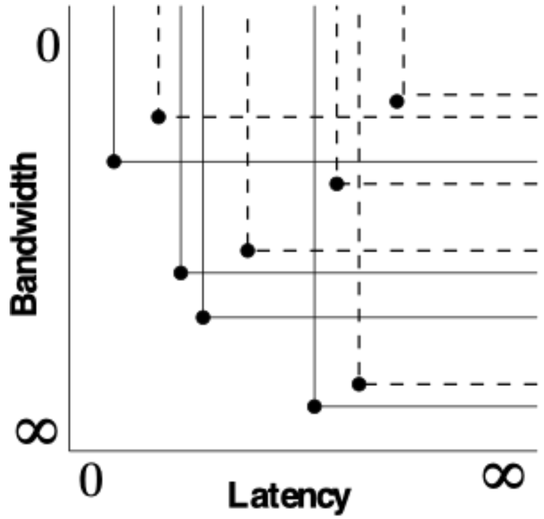

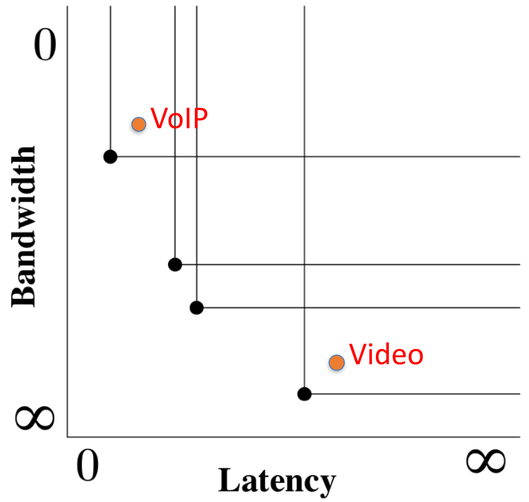

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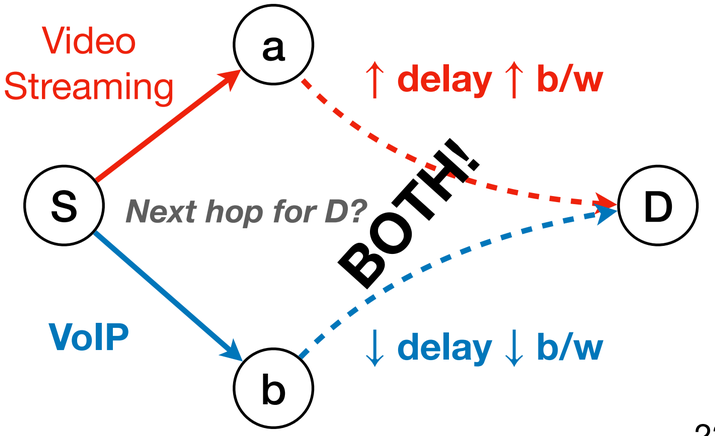

Categorical requirements using Boolean expressions - *Multitent*

Some Path Expressions

	TA	TB	**TA**	**TB**	**TA or TB**	**TA and TB**	**TRUE**	**FALSE**
1	*F*	*F*	***F***	***F***	***F***	***F***	***T***	***F***
2	*F*	*T*	***F***	***T***	***T***	***F***	***T***	***F***
3	*T*	*F*	***T***	***F***	***T***	***F***	***T***	***F***
4	*T*	*T*	***T***	***T***	***T***	***T***	***T***	***F***

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2	*F*	*T*	***F***	***T***	***T***	***F***	***T***	***F***
3	*T*	*F*	***T***	***F***	***T***	***F***	***T***	***F***
4	*T*	*T*	***T***	***T***	***T***	***T***	***T***	***F***

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4	T	T	T	T	T	T	T	F

Path Access of flow between TA and some node that is not in TB

	TA	TB	TA and ¬TB	TA	TB	TA or TB	TA and TB	TRUE	FALSE
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3	T	F	T	T	F	T	F	T	F
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- A constraint must be true for *at least one* of a path constraint's satisfying truth assignments.

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	TA	TB	TA and ¬TB	TA	TB	TA or TB	TA and TB	TRUE	FALSE
1	F	F	F	F	F	F	F	T	F
2	F	T	F	F	T	T	F	T	F
3	T	F	T	T	F	T	F	T	F
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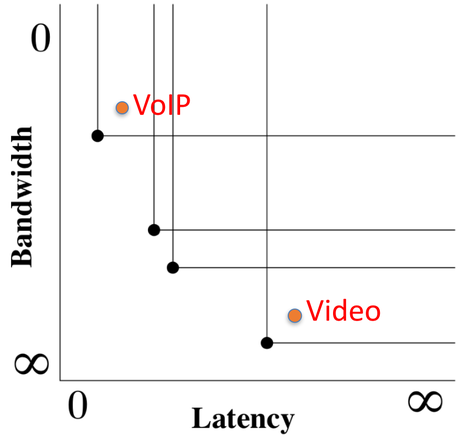
- A constraint must be true for *at least one* of a path constraint's satisfying truth assignments.
- Flow constraint *(TA and ¬TB)* is allowed for path expressions *TA*, *(TA or TB)*, and *TRUE*
- A flow can use a path if *the conjunction ('and'ing) of the flow and path constraints is* ***satisfiable***

Routing with Requirements… pulling it all together



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	TA	TB	TA and ¬TB	TA	TB	TA or TB	TA and TB	TRUE	FALSE
1	F	F	F	F	F	F	F	T	N
2	F	T	F	F	T	T	F	T	N
3	T	F	T	T	F	T	F	T	N
4	T	T	F	T	T	T	T	T	N

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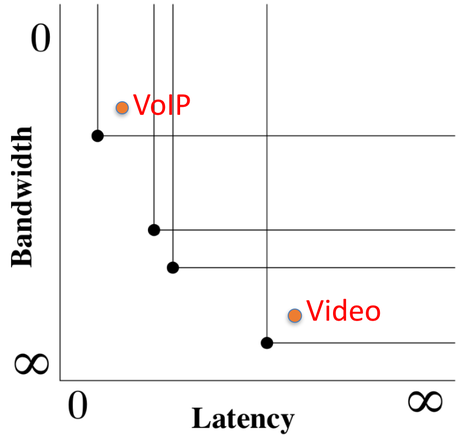


X

Path Access of flow between TA and some node that is not in TB

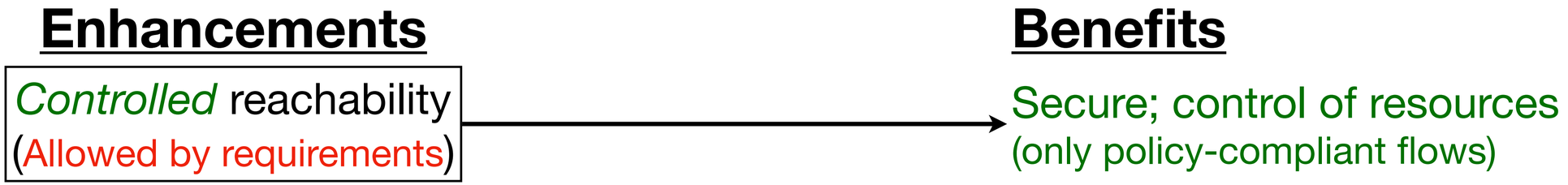
	TA	*TB*	*TA and ¬TB*	***TA***	***TB***	***TA or TB***	***TA and TB***	***TRUE***	***FALSE***
1	*F*	*F*	***F***	***F***	***F***	***F***	***F***	***T***	N
2	*F*	*T*	***F***	***F***	***T***	***T***	***F***	***T***	N
3	*T*	*F*	***T***	***T***	***F***	***T***	***F***	***T***	N
4	*T*	*T*	***F***	***T***	***T***	***T***	***T***	***T***	N

In effect, compute and use the ***dominant set of paths…*** for each satisfying truth assignment.

Benefits of Routing with Requirements

Enhancements	Benefits

Benefits of Routing with Requirements



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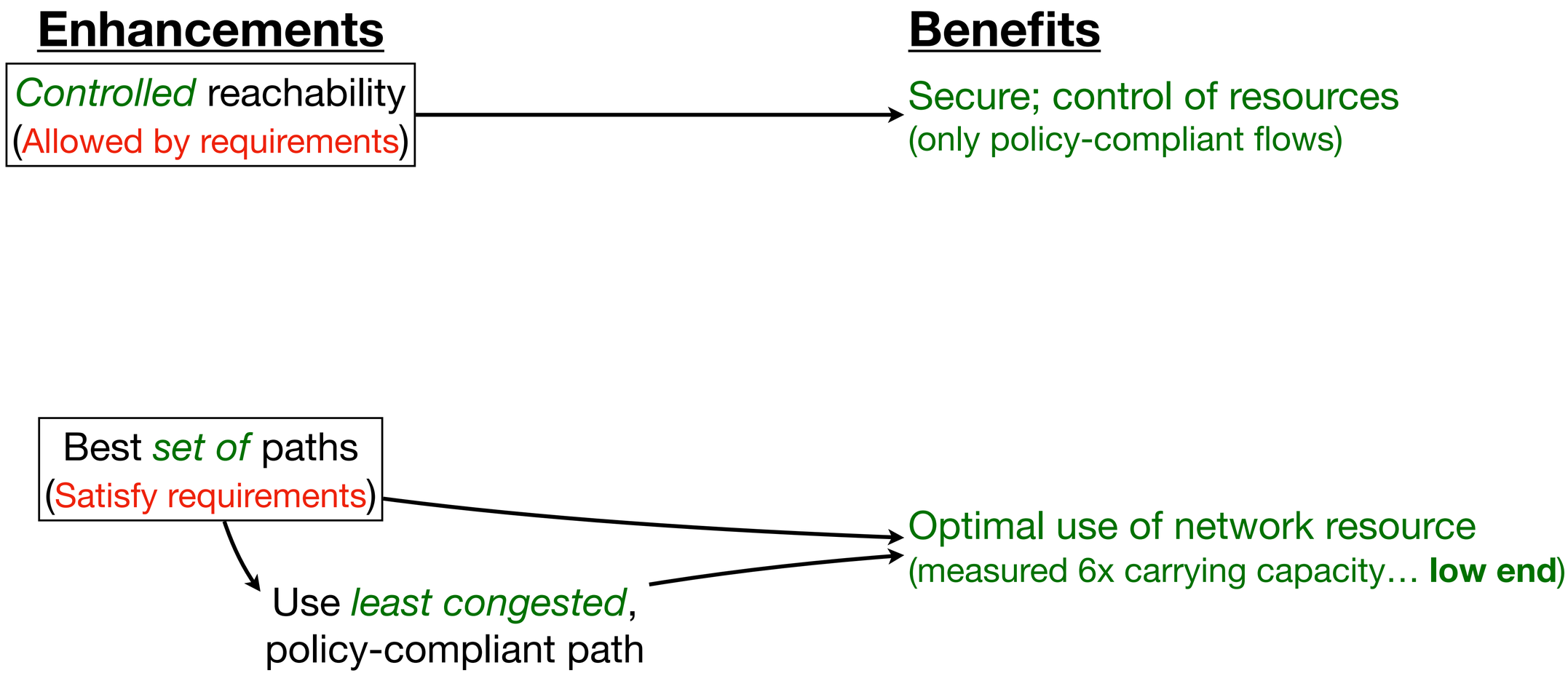

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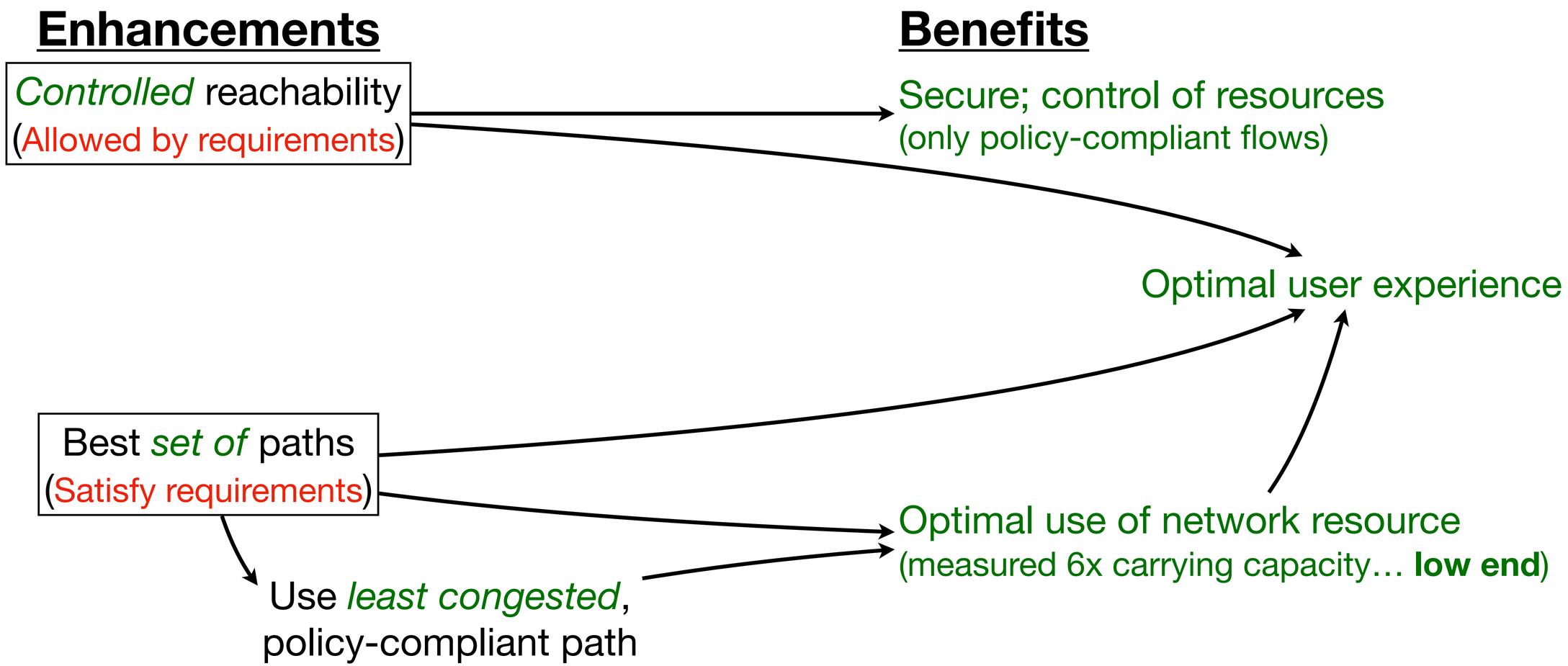

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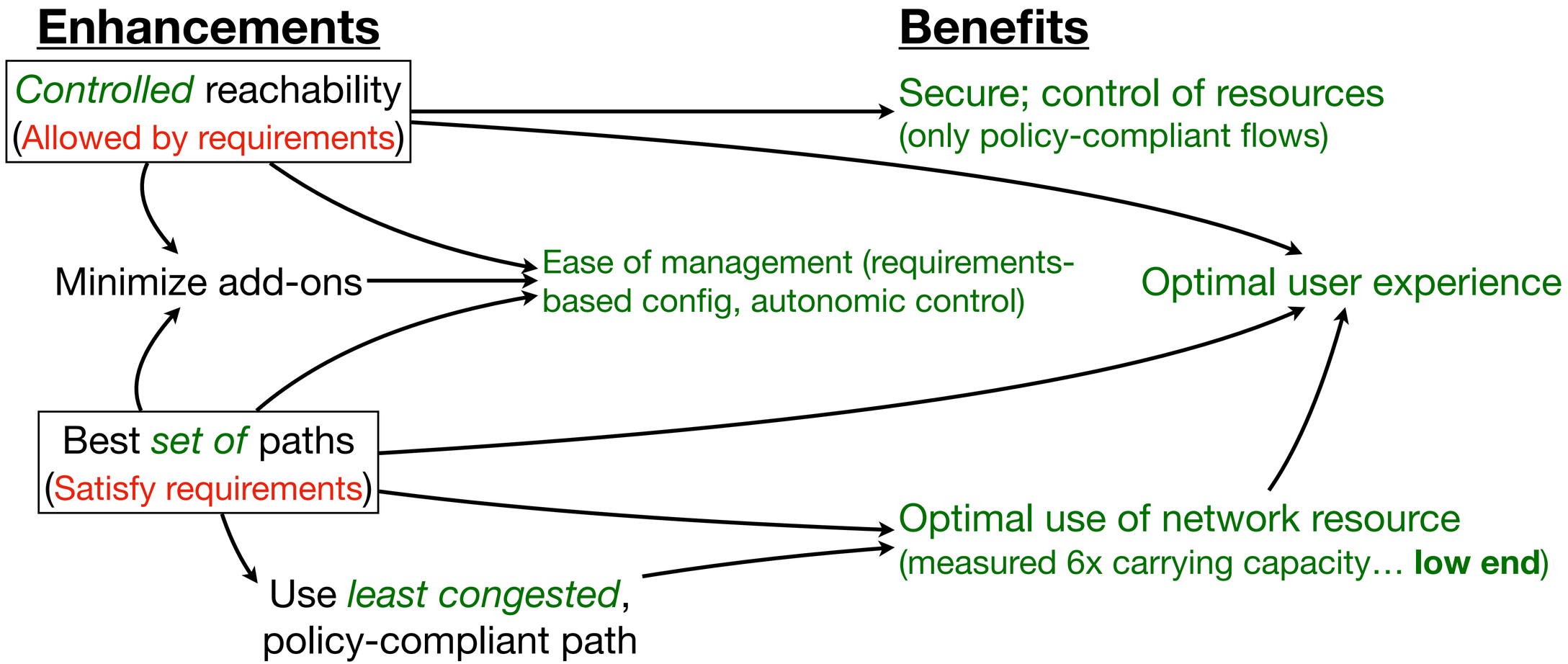

Problems with the original Internet

Proposed Solution
Routing with requirements

Benefits

Testbed & Summary

Test Lab results *untuned* Prototype (3x3 torus)

"Evaluation of NwC features like QoS, Zero Trust, and Network Segmentation – verified to meet expected results. The NwC controller efficiently uses the flow table resources by deleting flow table entries that haven't been used for a period of time."

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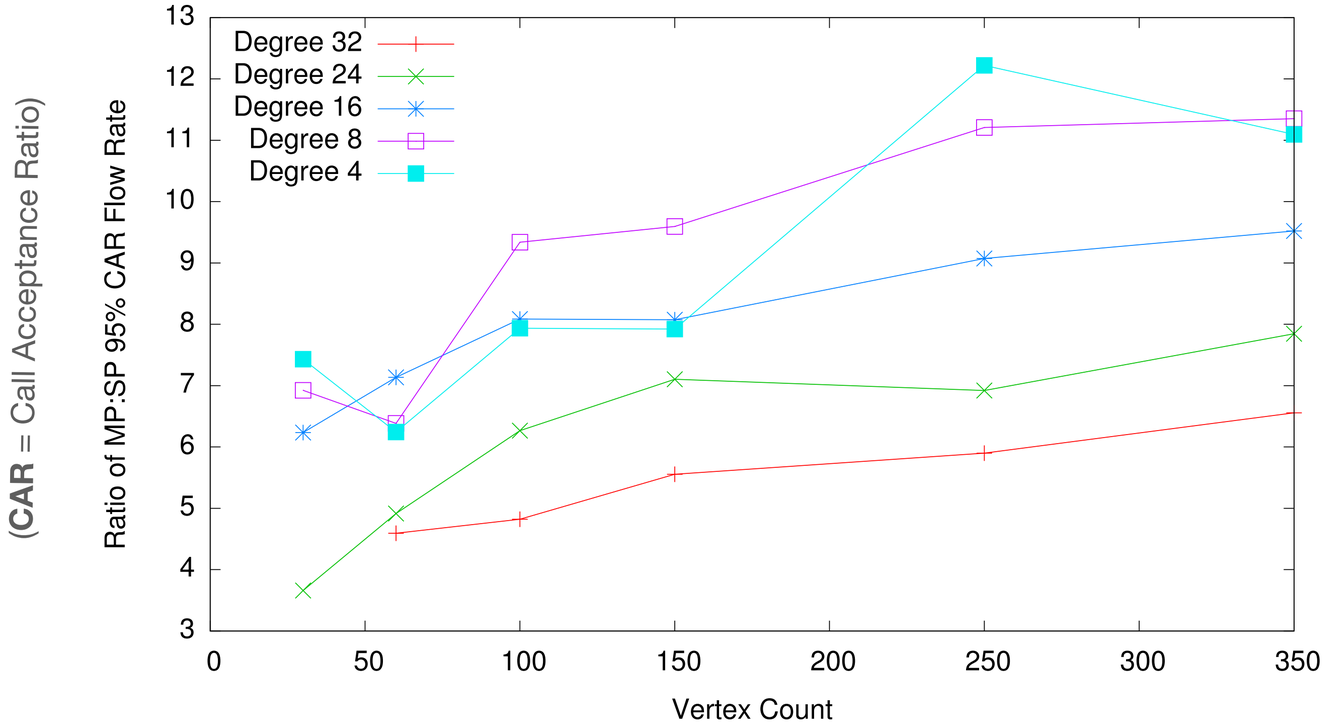

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- Requirements defined by user, application, network admin
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- Benefits
  - Secure
  - Optimize user experience (policy-compliant flows)
  - Optimize use of network resources
  - Intuitive configuration
  - Autonomic control (Boolean variables)… threat level, roles, schedule, etc.
  - Many applications… Zero Trust, network segmentation, 5G slices, IPMS, …

Summary - Routing with requirements

- Requirements defined by user, application, network admin
- Works over anything… *exploits special functionality when it's available!*
- Benefits
  - Secure
  - Optimize user experience (policy-compliant flows)
  - Optimize use of network resources
  - Intuitive configuration
  - Autonomic control (Boolean variables)… threat level, roles, schedule, etc.
  - Many applications… Zero Trust, network segmentation, 5G slices, IPMS, …
- Implementation options… network/link layer, controller/distributed

For questions, to express interest in collaborating, or to request online access to the prototype (only requires a web browser) contact me at:

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