Network Optimization via Path Selection in a Heterogeneous Cloud-Based Internet of Things

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Group Meeting

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Outline

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Purpose/Motivation

- 2019: Cisco predicts > 500 zettabytes of Internet traffic/year
  - 1 zettabyte = 10^{21} bytes = 1 billion TB = 1 trillion GB
- 2020: > 50 billion connected devices, cloud consumption will increase 4x by 2020 to 8.6 zettabytes, enterprises plan to transfer 56% of applications and data to cloud
- M2M Devices: 30% of all connected devices today to 46% in 2020, but only ~ 2-4 % of traffic
- Will IoT simply require more physical layer core capacity? Or will traffic nature and increased heterogeneity require more robust traffic engineering and/or policy based/constraint-based routing?

http://siliconangle.com/blog/2015/10/28/cisco-predicts-internet-of-things-will-generate-500-zettabytes-of-traffic-by-2019/

http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/vni-hyperconnectivity-wp.html

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Problem Statement

1st Priority: Optimize performance metrics of a set of traffic flows w/ heterogeneous application & traffic profiles via path selection within a core layer internetwork.

Solution form: Unique path for each node pair & application profile, intended to generate diverse set of SLAs for each node pair

2nd Priority: Given above path solutions by node pair, minimize operational cost to MAN service provider while maintaining end to end performance requirements. Simulate various application profile mixtures and loads; determine at what loads performance is substantially degraded. Repeat for various link capacities (higher costs).

3rd Priority: Inject a multi-homed redundant 4G/5G connection from specific sensors/sink node to specific nodes in access/metro layer

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Functional Based Application Requirements

- Each application requires various tiers of data processing capability prior to delivery to final destination
- Applications may require storage at DC
- Interactive applications: location of the client (and thus the path metrics) will affect the computation location
- Traffic may be aggregated from multiple sources for a single event

Storage Required	Processing Required	Cause	Source	Destination
None	None	Primary Event	Single Sensor	Single Sensor
Data Center	Tier 1- Sink/GW	Secondary Event	Multiple Sensors	Multiple Sensors
	Tier 2	Client Demand	DC	DC
	Tier 3 - DC	Periodic to DC	Client	Client
		Periodic to Client		

Application Performance/Cost Requirements

Latency	Bandwidth	Reliability	Jitter
Uni-directional: < 50 ms	Min 50 Mbps per link	Prob. Delivery: > 99.9%	Latency +/- 10%
Bi-directional: < 100ms		Path of Least Congestion	Latency +/- 20%

Upstream to Internet	Downstream from Internet	Storage	Processing (Tier I, II, III)
X dollars per Mbps	X dollars per Mbps	X $ per Mbit	I: X dollars per Mbps (high)
			II: X dollars per Mbps (moderate)
			III: X dollars per Mbps (low)

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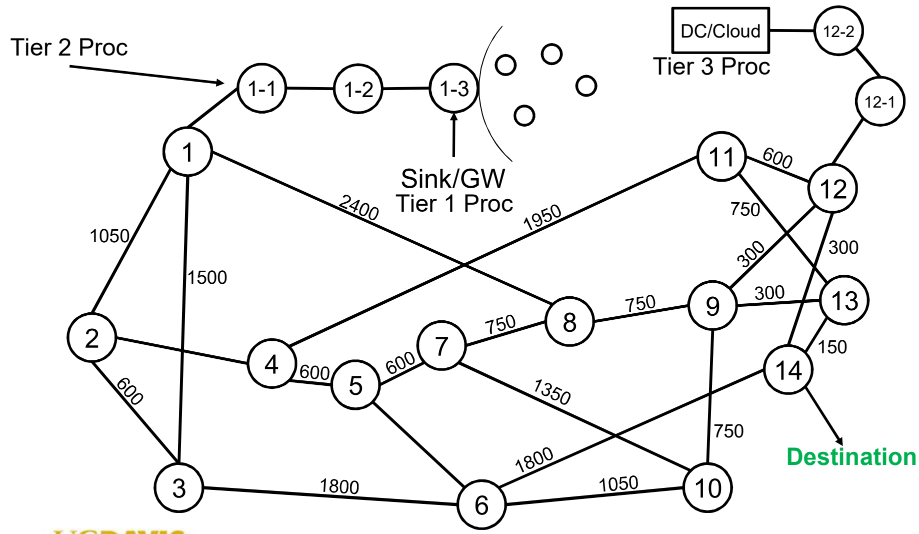
NSFnet Topology



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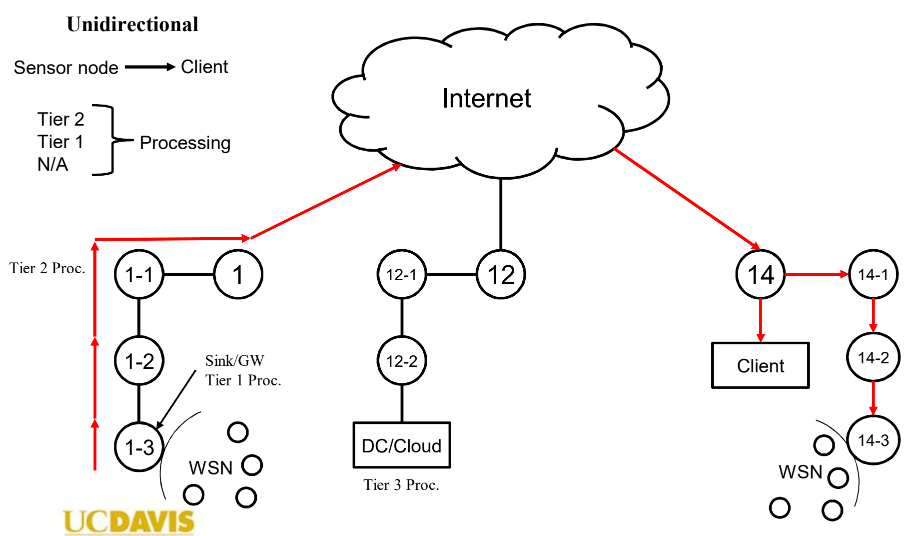
Flow Scenarios



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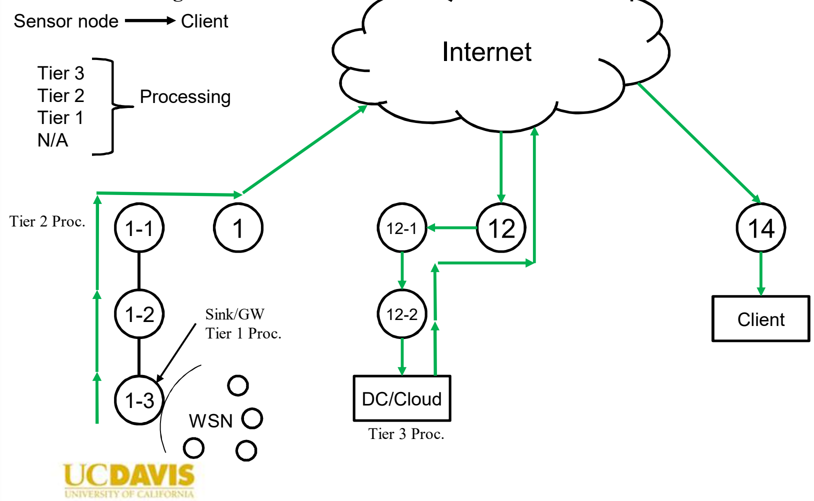
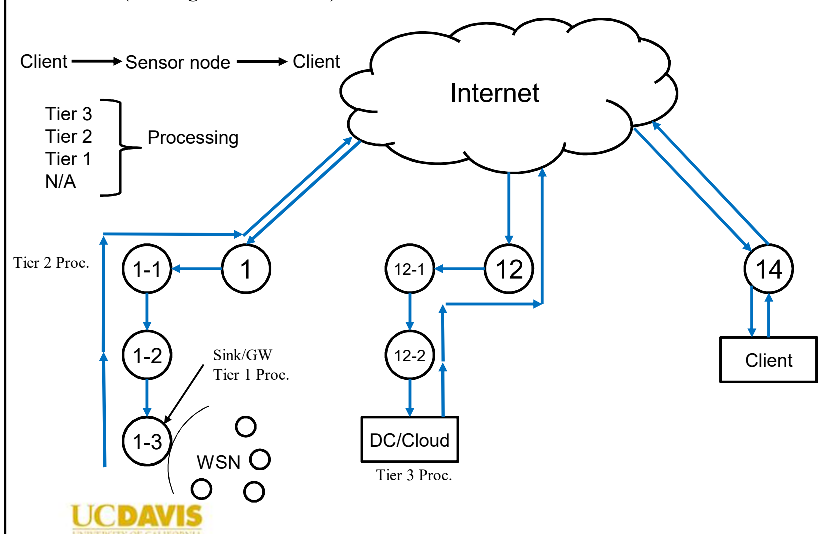
Flow Scenarios (cont.)

Unidirectional – w/ Storage and/or Tier 3 Processing

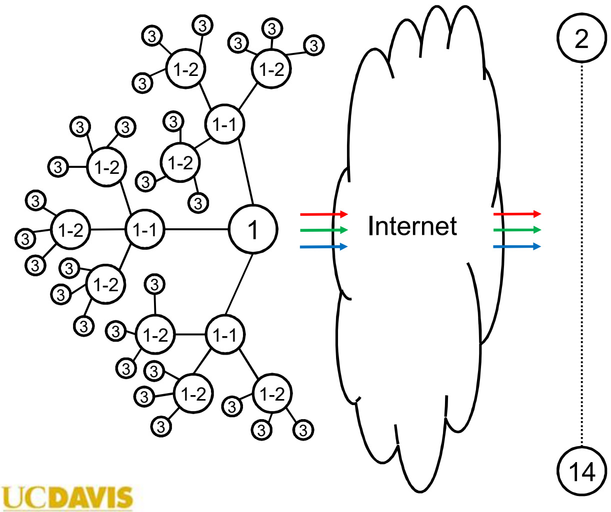


Flow Scenarios (cont.)

Interactive (Through DC or direct)



Flow Scenario Visualization



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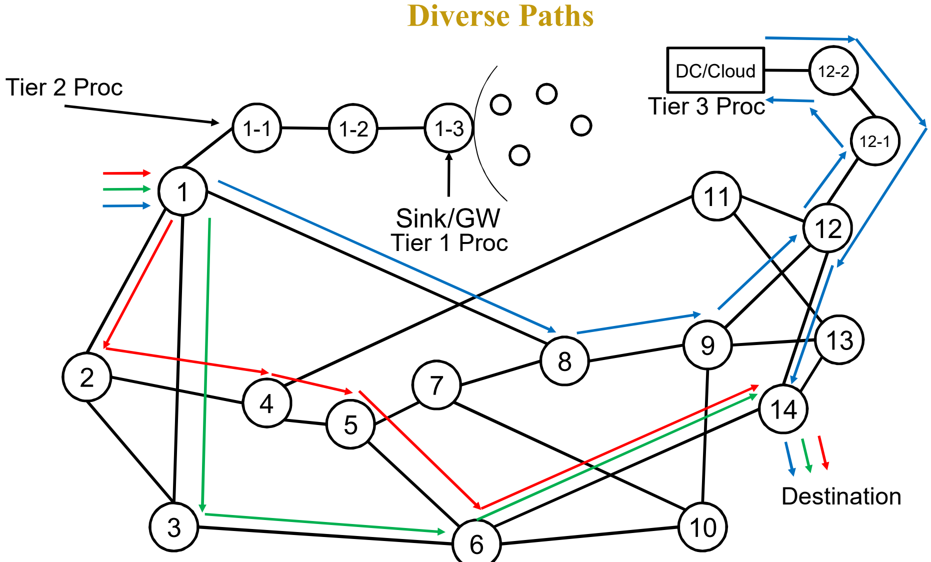
Diverse Paths



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Mathematical Formulation

Variables:

$v_{c,a}$: Offered traffic of application profile **a**, between node pair **c**.

$r_{c,k,a}$: Traffic of application profile **a**, routed over the $\mathbf{k}^{th}$ admissible path between node pair **c**.

$S_{a,i} = 1$, if traffic of application profile **a** requires storage at DC, located behind node **i**

$d_{t,i,j}$: Transmission delay at node **i** on link **i j**

$d_{p,i,j}$: Propagation delay on link **i j**

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Mathematical Formulation (cont.)

Variables:

$d_{n,i}$: Processing delay at node **i**

$K_{c,a}$: Set of all admissible paths between node pair **c** for appl **a**

$k_{c,a}$: $\mathbf{k}^{th}$ admissible path between node pair **c** for appl **a**

$h_{c,k,a}$: Hop count of $\mathbf{k}^{th}$ admissible path for node pair **c**, appl **a**

$P^{c}_{a,t} = 1$, if traffic of application profile **a** between node pair **c** is processed at tier **t**

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Mathematical Formulation (cont.)

Variables:

$\kappa_{a,t,c}$: Tier **t** processing cost per unit of traffic of application profile **a** between node pair **c**

β_a: Parameter that defines relationship between computational power required and traffic of application profile **a**

ν_a: Cost per unit of traffic of application profile **a** for data center storage

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Mathematical Formulation (cont.)

Objective Function:

$$\max \prod_{c=1}^{N(N-1)} \prod_{a=1}^{A} \frac{Perf_a^c}{Cost_a^c}$$

$Perf_a^c$ and $Cost_a^c$ are Performance and Cost functions of **A** application profiles between each node pair **c**.

Subject to:

$$\sum_k r_{c,k,a} = v_{c,a} \ \forall (c,a)$$ Solenoidality

$$\sum_a \sum_{r_{c,k \in R_{i,j}}} r_{c,k,a} \le F_{i,j} \quad \forall (i,j)$$ Capacity

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Mathematical Formulation (cont.)

$$\sum_{t=0}^{3} P^c_{a,t} = 1 \;\forall (a,c)$$ Processing

$$i \in k_{c,a} \text{ if } S_{a,i} = 1 \;\forall (a,c)$$ Storage

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Mathematical Formulation (cont.)

Performance Functions:

Total Latency (uni-directional):

$$Perf^c_1 = \sum_{(i,j)\in k_c} d_{p,i,j} + \sum_{(i,j)\in k_c} d_{t,i,j} + \sum_{(i)\in k_c} d_{n,i}$$

Total Latency (bi-directional/interactive):

$$Perf^c_2 = 2(\sum_{(i,j)\in k_c} d_{p,i,j} + \sum_{(i,j)\in k_c} d_{t,i,j} + \sum_{(i)\in k_c} d_{n,i})$$

Min Throughput Link x Total Latency

$$Perf^c_3 = (min \sum_{r_{c,k\in R_{i,j}}} r_{c,k,3})(\sum_{(i,j)\in k_c} d_{p,i,j} + \sum_{(i,j)\in k_c} d_{t,i,j} + \sum_{(i)\in k_c} d_{n,i})$$

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Mathematical Formulation (cont.)

Cost Function:

$$Cost_a^c = \alpha_{u,a}^{s_c} v_a^c + \alpha_{d,a}^{d_c} v_a^c + v_{c,a} \sum_{t=0}^{3} \kappa_{a,t}^c P_{a,t}^c + \nu_a S_{a,i} v_{c,a}$$

Upstream, Downstream, Processing, Storage

$\alpha_{u,a}^{d_c}$ = Cost per unit of upstream traffic of application profile **a** from source of node pair **c**

$\alpha_{d,a}^{d_c}$ = Cost per unit of downstream traffic of application profile **a** to destination of node pair **c**

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Mathematical Explanation

Inputs: Performance functions based on the application profiles
Cost functions
Single/multiple cloud storage/DC locations
Multiple data processing locations
Topology, profile proportions at each source node (1/4, ¼, ½)
Link Capacities

Objective function: Maximize product of performance/cost ratios via ideal paths of heterogeneous application traffic flows across all possible node pairs.

Outputs: For each node pair and application profile:
Designated path through core nodes
Intermediate processing location, if necessary

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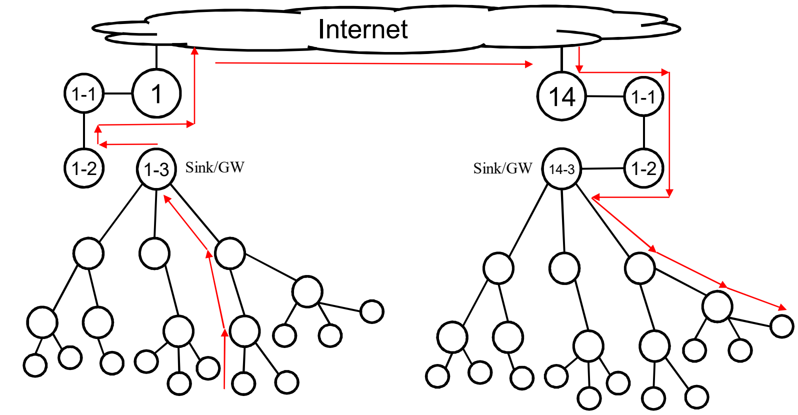
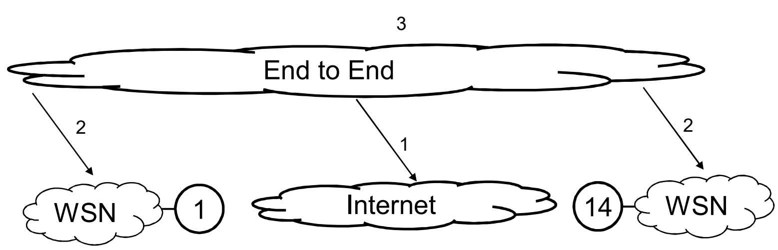
WSN/Core Integration



Logical (tree) topology in a WSN computed based on RPL

Optimized path selection per application profile can be based on the core network ILP solution

WSN/Core Integration



Future Work

ILP Solution: Ideal paths that maximize performance/cost ratio for all node pairs and application profiles

Formulate similar ILP for internal WSN path selection; determine feasibility of integration

Compute integrated (complete end-to-end) best path solution

Dynamic simulation: Given ILP solutions, simulate dynamic traffic to determine time varying delay (jitter) and other performance metrics in order to formulate strategy for further optimization.

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References

1. http://siliconangle.com/blog/2015/10/28/cisco-predicts-internet-of-things-will-generate-500-zettabytes-of-traffic-by-2019/
2. http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/vni-hyperconnectivity-wp.html
3. Parwekar, P., 2011, September. From internet of things towards cloud of things. In *Computer and Communication Technology (ICCCT), 2011 2nd International Conference on* (pp. 329-333). IEEE.
4. 2. Bonomi, F., Milito, R., Natarajan, P. and Zhu, J., 2014. Fog computing: A platform for internet of things and analytics. In *Big Data and Internet of Things: A Roadmap for Smart Environments* (pp. 169-186). Springer International Publishing.
5. 3. Borges, L.M., Velez, F.J. and Lebres, A.S., 2014. Survey on the characterization and classification of wireless sensor network applications.*IEEE Communications Surveys & Tutorials*, *16*(4), pp.1860-1890.
6. 4. Botta, A., Pescapé, A. and Ventre, G., 2008. Quality of service statistics over heterogeneous networks: Analysis and applications. *European Journal of Operational Research*, *191*(3), pp.1075-1088.
7. 5. Fox, G.C., Kamburugamuve, S. and Hartman, R.D., 2012, May. Architecture and measured characteristics of a cloud based internet of things. In*Collaboration Technologies and Systems (CTS), 2012 International Conference on* (pp. 6-12). IEEE.

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