

Barriers and Frontiers of Softwarization and Management for the Network of 2030

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(Softwarized) Networks in 2030

- New Services
 - Industry 4.0: long-distance industrial control and cyber-physical systems – deterministic, time-guaranteed services
 - VR/AR → Holographic-Type Communications
 - Tactile Networking
- New Infrastructure
 - IoT/E: Billions and billions of things
 - Satellite / terrestrial integration
 - V2X
- New Verticals and Business Models



Image references:

<https://disruptionhub.com/innovation-industry-4-0/>

<https://themarketfact.com/2019/05/22/global-holographic-display-market-2019/>

Common themes

- Stringent Service Level Requirements
 - Extremely low latencies, coupled with high bandwidth + low loss
 - Tactile feedback: $o(<2\text{ms})$ round-trip latency
 - Holographic-Type Communications: Gbps \rightarrow Tbps, $o(30\text{ ms})$ round-trip for user interaction-based optimization schemes
- Mission-Criticality
 - Guarantees and validation beyond “best effort”, “optimization”, “prioritization”
- Unprecedented Scale
 - Smart spaces, ambient communications, IoE
- Other themes
 - Agility: Vendor defined \rightarrow Operator Defined \rightarrow User Defined
 - Decentralization and federation (necessitated through latency requirements)
 - Privacy



Tactile Operator
(Client)



Actuators & Sensors
(Server)

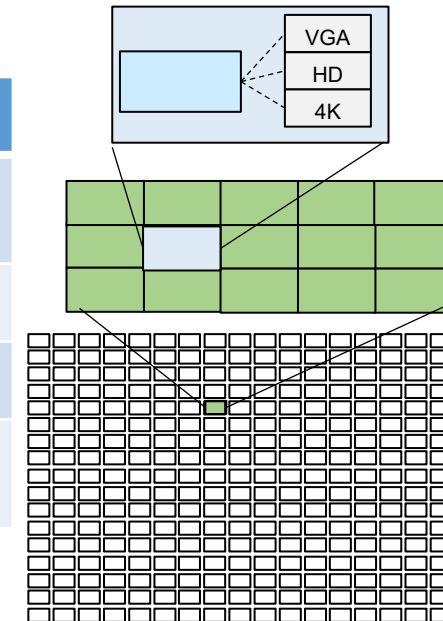


images reference:

<http://www.boonvr.com/data/blog/2017/12/19/history-of-vr/>

<https://pixels.com/featured/pr2-robot-hand-holding-an-egg-patrick-landmann.html>

Image	#dim	Variables
Still picture	2	Image resolution, color depth
Video	3	Add framerate
VR	4	Add tiles
HTC	5..7	Add 6DOF (angle, tilt, depth)



Barriers and Frontiers: Visibility

- You cannot control/ manage (let alone guarantee) what you cannot observe/ measure
 - Accuracy
 - Unprecedented service level guarantees require unprecedented accuracy in measurements, telemetry
 - Scope
 - How to explain behavior observed against a flow? What happens in the life of a packet?
 - From “entity”-based (eg. device, node, function) to “end-to-end”-based (eg. streams, flows, paths)
 - Span of abstraction
 - From “Big picture” for human operators, visualization/reporting to low-level understanding of forensic details
- Requires significant advances in:
 - Measurement technology
 - Accuracy:** ms→us, error rates: 10^{-6} → 10^{-12} , **Coverage** (beyond sampling limitations)
 - Instrumentation (from devices and interfaces, to flows and packets)
 - Telemetry (generation, aggregation of actionable data at scale as needed)
 - IOAM data alone (packet data with per-hop stats) can easily outgrow production traffic
 - Feature reduction, automatic adaptation of input data, smart aggregation
 - Note: many things will still be dumb in 2030 – little intelligence to support you, poor signal-to-noise ratio

Barriers and Frontiers: Control

- Scaling runtime (management, control) and development time (expertise, algorithm)
 - Beyond Automation and Devops
 - AI+ML for tuning, optimization, selected control decisions
e.g. path selection, admission control
 - Control logic: automatic determination, configuration of paths, service function chains
from classification/regression to planning, game-theoretic optimization
- One promising approach: Intent-based management
 - Network infers and anticipates what operators need
 - **Outcome-based**, not instruction or rule-/policy-based – systems may learn their own algorithms
(cp Machine Learning vs Expert Systems)
 - Note: taken up by IRTF NMRG
- Requires significant advances in:
 - Expression and articulation of intent – novel human/machine UIs
 - Automatic explanation of control actions, of observations
 - Integration with analytics and assurance
 - Assess effectiveness of automated actions
 - Recognize “intent drift”
- **Where is the Alpha Go for Network Controllers and OSS?**



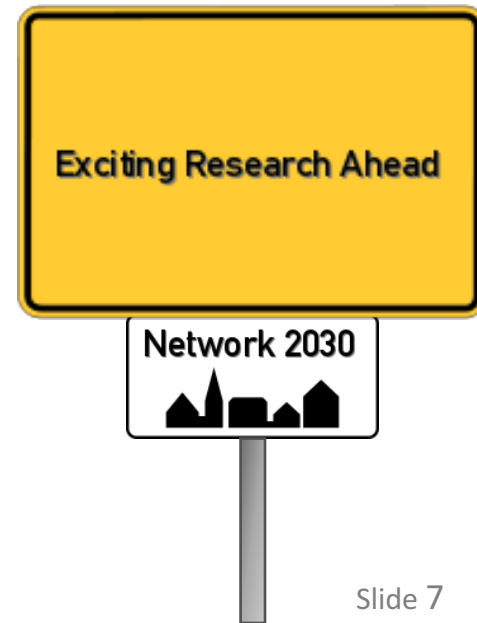
image reference: <https://futurism.com/google-unveils-ai-learns>

Barriers and Frontiers: Other aspects

- Accounting and Accountability
 - New value chains may enable new business models and require new accounting schemes
 - Incentive-based schemes to deliver on service levels
 - Integrated proof-of-delivery and escrow schemes
- Managing Privacy
 - Control dissemination and geo paths, track leakage, proof of compliance
- Programmability and novel programming models
 - E.g. user-defined flow programming & flow intent from the edge
- Softwarization interplay with hardware advances
 - Performing advanced functions at line rate: map to hardware pipelines
 - Concurrency and non-blocking schemes:
e.g. perform analytics without slowing down forwarding functions

Next Steps & Conclusions

- Network 2030 imposes significant barriers and frontiers
- Visibility into the network crucial for management and control loops
 - Advances needed in accuracy, scale, instrumentation to manage novel extremely time-sensitive services
 - Increased focus on end-to-end artefacts: streams, flows, paths, packets
 - Solution components will include Smart Telemetry Streaming, IOAM, Operational Flow Profiling
 - Visibility and data is the fuel for analytics & learning
- Management and Control needs to move beyond mere automation
 - Intent as one key to transition from imperative & rule-based automation to **outcome**-based management
 - Complement with novel network programming models: from vendor-defined (past), to operator defined (SDN – present), to user-defined (future)
 - Solution components will include AI-based controllers, novel network protocols (e.g. BPP)
- It is an exciting time to be a researcher!



Thank you!