Network 2030:
Market Drivers and Prospects

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Oct. 2nd, 2018

Agenda

- Internet
  - 1960-2000
  - 2000-2020
  - 2020-2030
- New Market Drivers
- Limitations of Current Internet
- New Communication Services
- Prospects for Network 2030

Acknowledgements:

- Thanks to many colleagues and friends all over the world who have helped me in this work.
- Some pictures/images come from the Internet. Thanks to their original authors.

The Internet in 1960-2000
one of the most important technical achievements

Paul Baran

Inventor Packet Switching

Leonard Kleinrock

Frank Heart &Team,

BBN IMP Spec

Queen Elizabeth II

Sends her first email.

TCP/IP Standardized

ARPANET ceased

1961 — 1965 — 1968 — 1974 — 1976 — 1979 — 1980 — 1989 — 2000

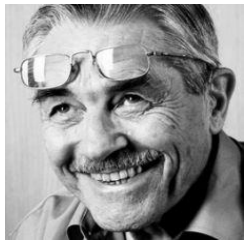
Conceptual — **Experimental** — **Standardization** — **Exploooooosion**

Inventor Packet Switching

Don Davis, NPL, UK

Cyclades at INRIA, France, 1971-1979,

Louis Pouzin



IEEE, "A Protocol for Packet Network Intercommunication" , 1974

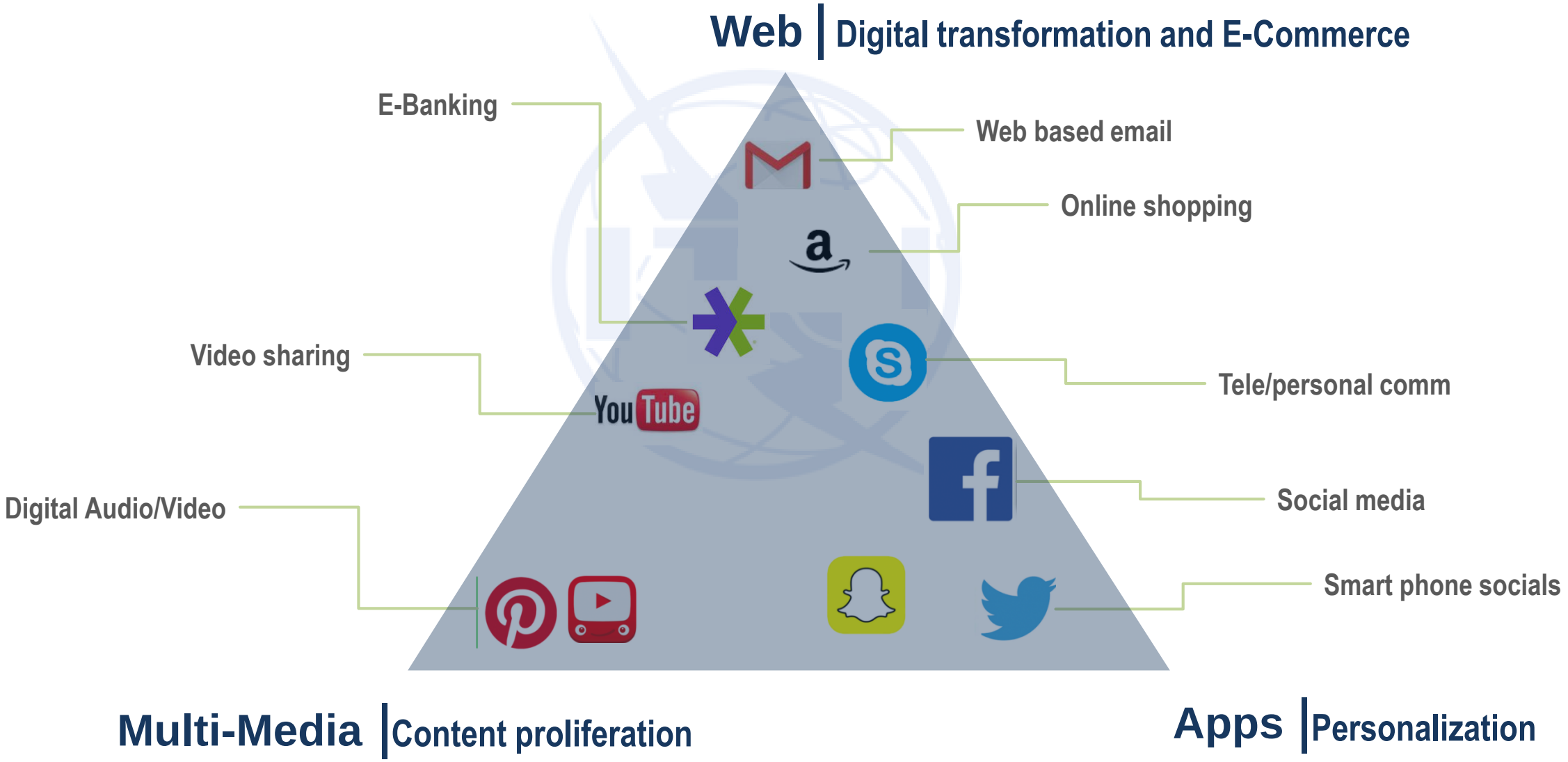
Vinton Cerf and Bob Kahn

WWW, CERN

Tim Berners-Lee

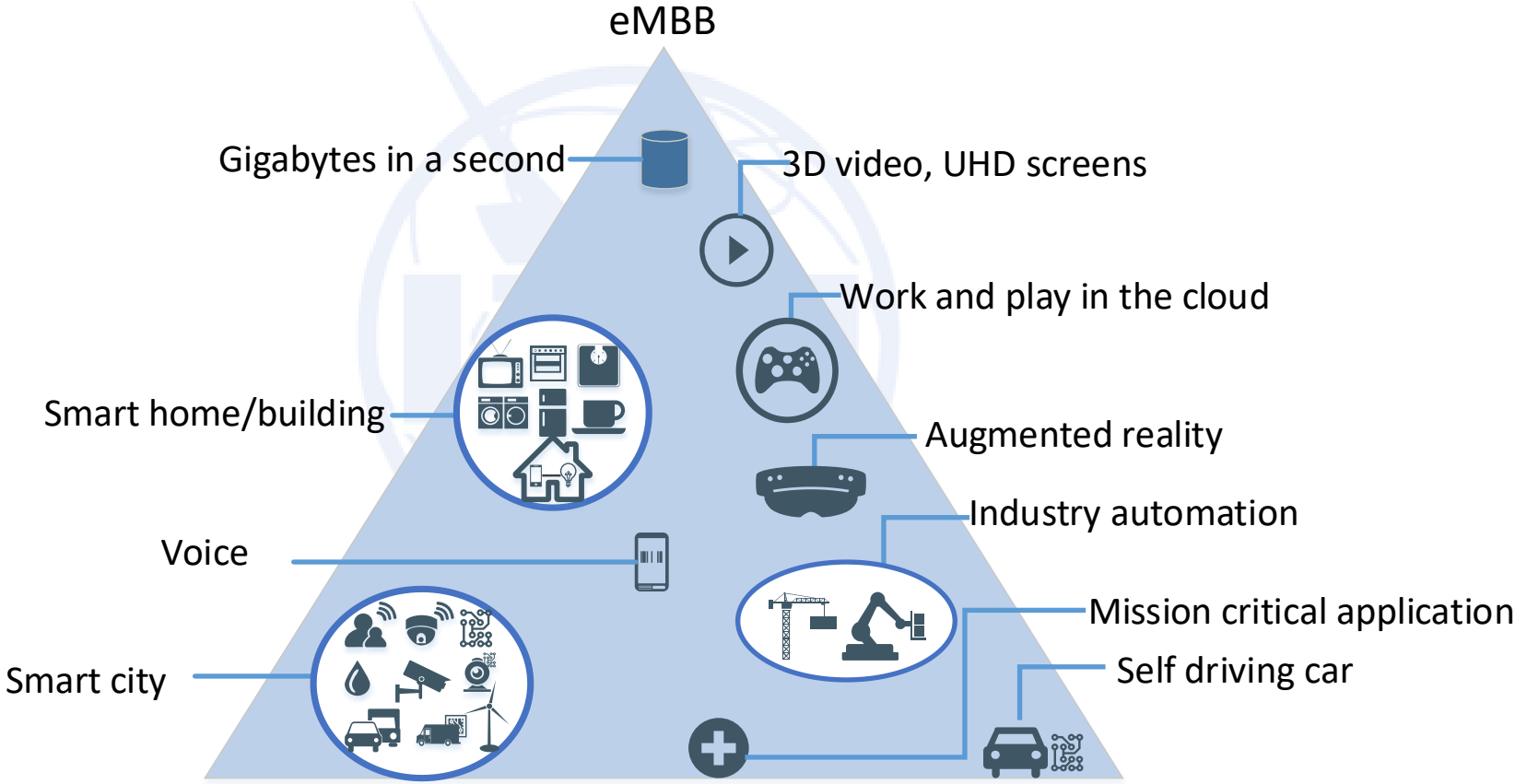
Packet Switching | **Landmark Projects** | **Commercialization**

The Internet in 2000-2020



What happens in 2020-2030

Abundant Bandwidth Everywhere



Connectivity for Everything

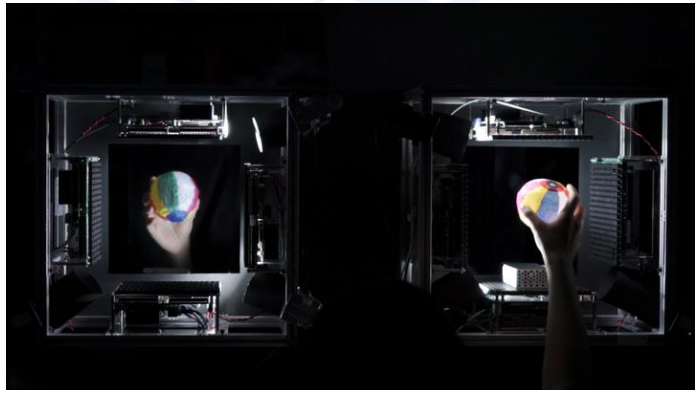
Critical Applications and Services

Source: ITU-T IMT-2020

New technologies are emerging in 2030 and thereafter?

Digital Senses and Reality

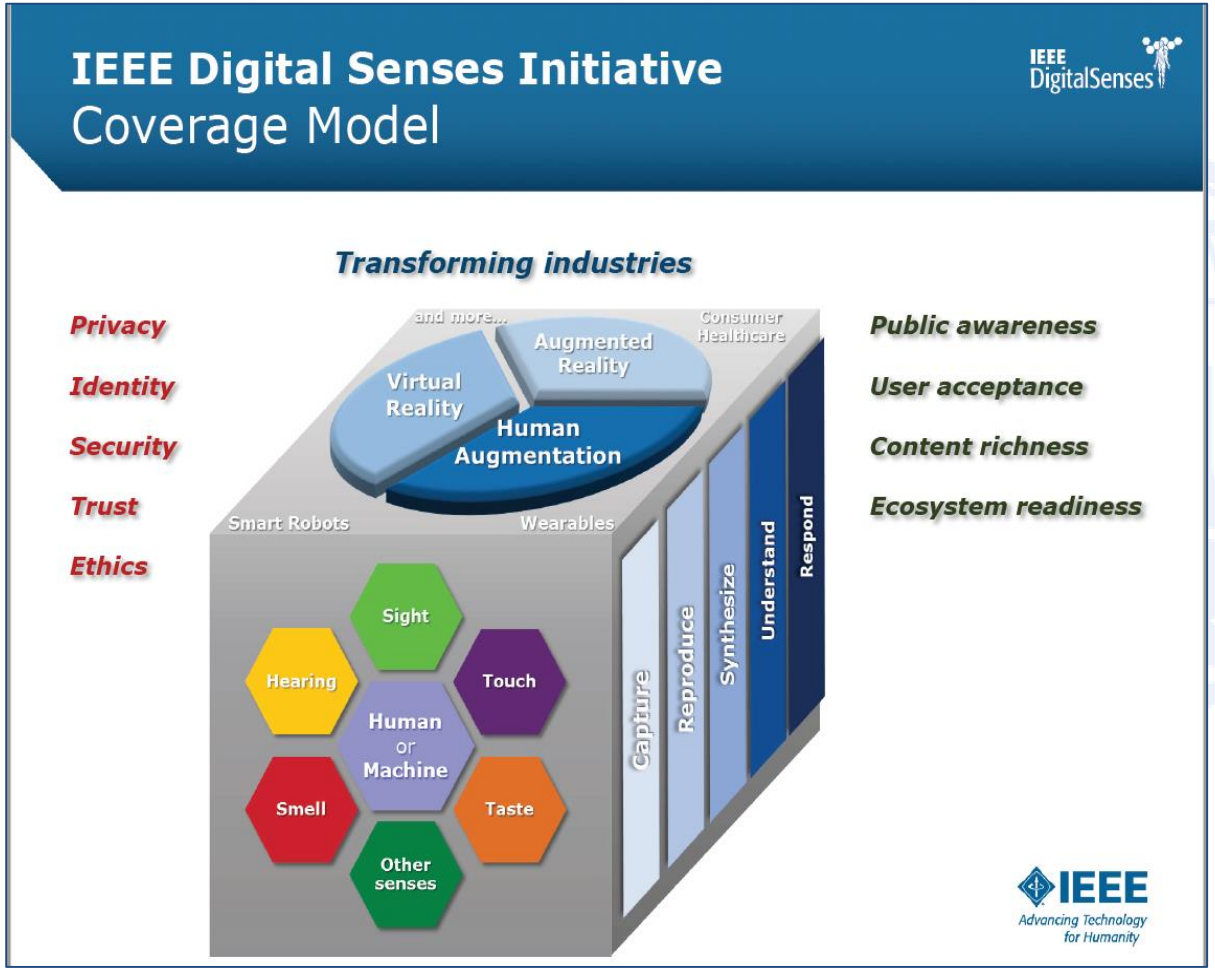
Haptic Technologies and Terminals

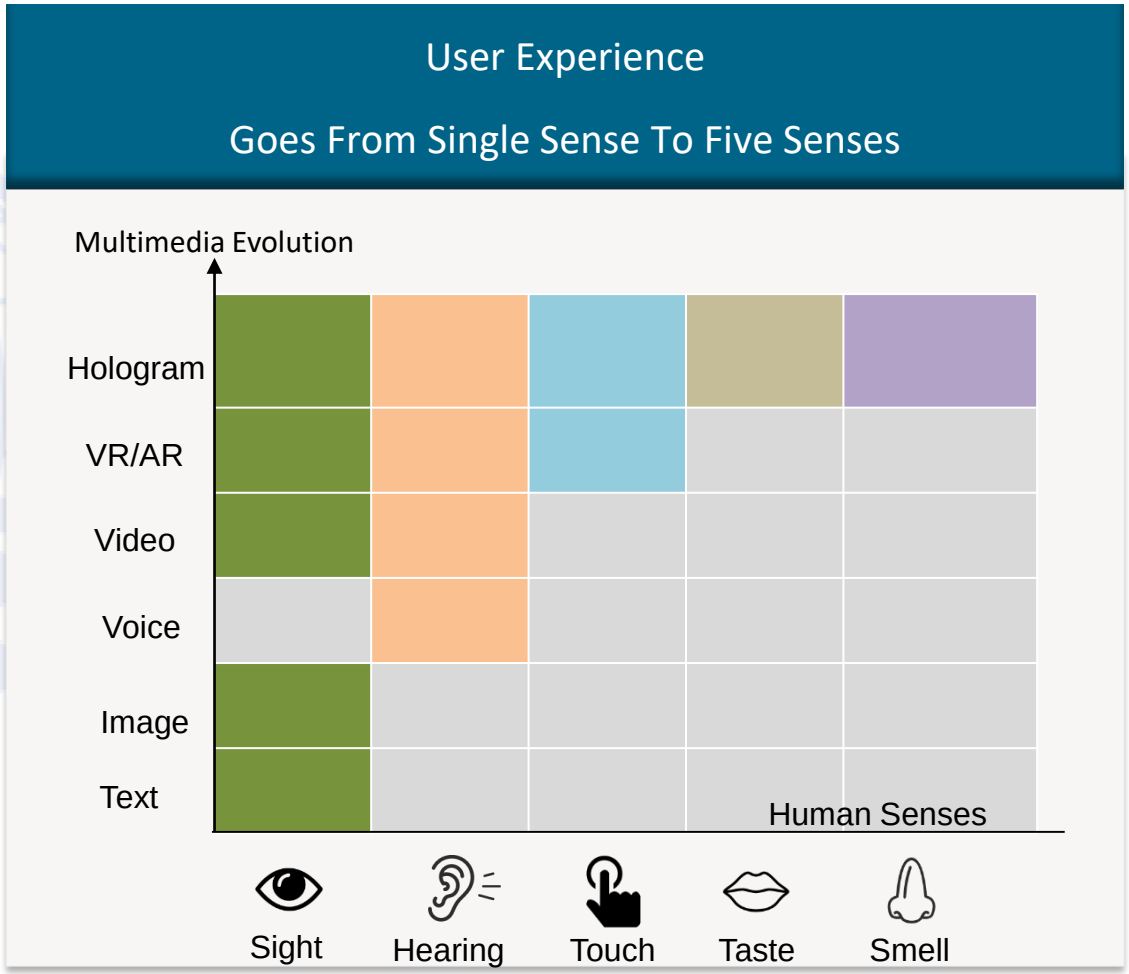


Holographic Verticals and Society

Image Sources: Internet, ACM, IEEE, ABC

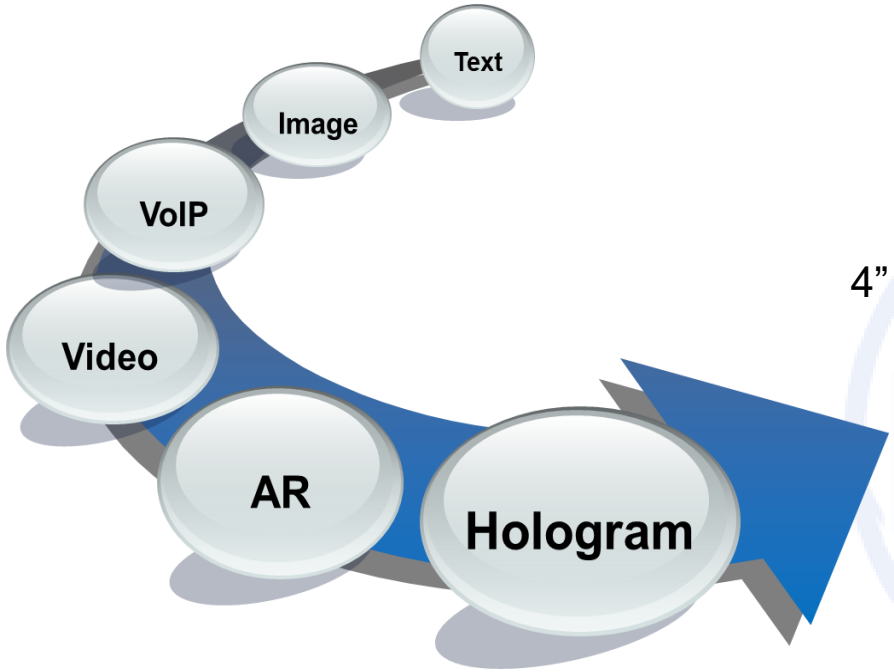
Digital Senses and Digital Reality

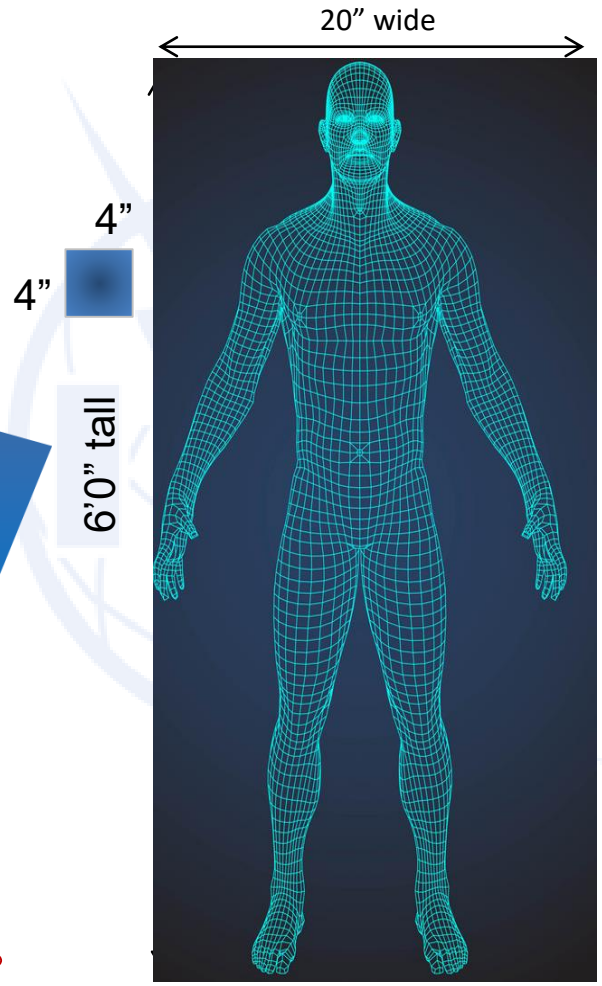




- Well explored: sight, hearing
- Emerging: touch, taste, smell

Is the Internet Ready for Holographic Challenges?





	Dimensions	Bandwidth
Tile	4 x 4 inches	30 Gbps
Human	72 x 20 inch	4.32 Tbps

- Raw data; no optimization or compression.
- color, FP (full parallax), 30 fps

(reference: 3D Holographic Display and Its Data Transmission Requirement, 10.1109/IPOC.2011.6122872), derived from for ‘Holographic three-dimensional telepresence’; N. Peyghambarian, University of Arizona)

Throughput goes up higher and higher

4K/8K HD		VR/AR		Hologram
35Mbps~140Mbps	band width	25Mbps~5Gbps	band width	4 Tbps~10 Tbps

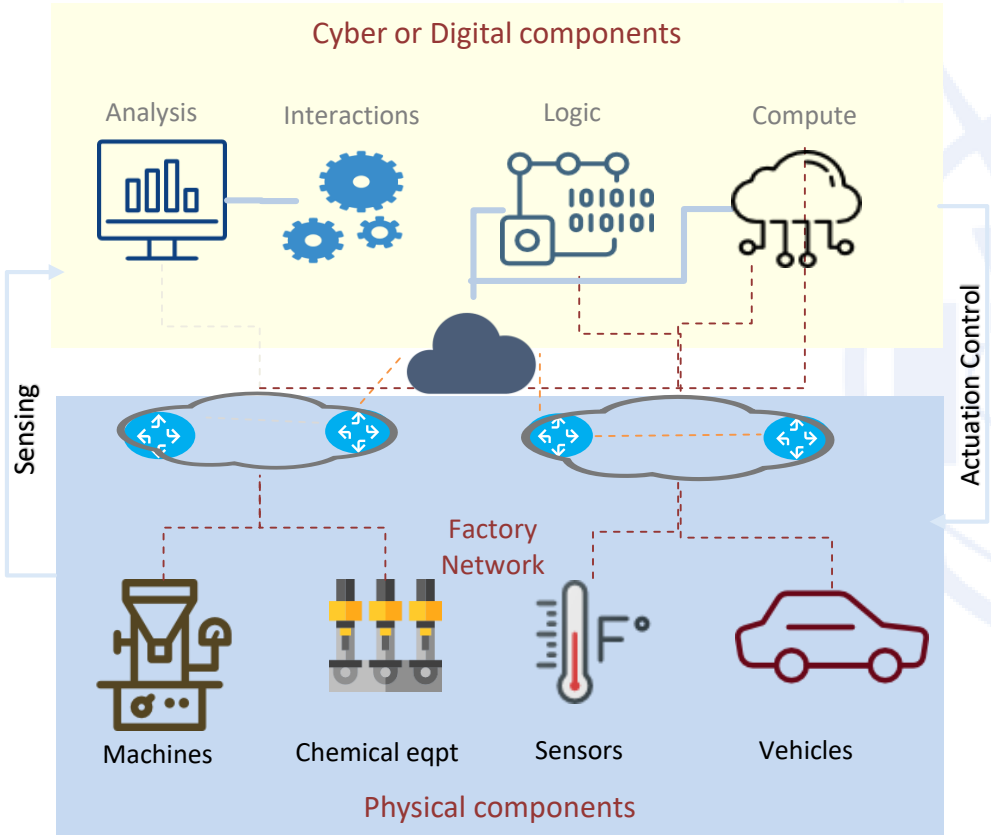
Latency falls down lower and lower

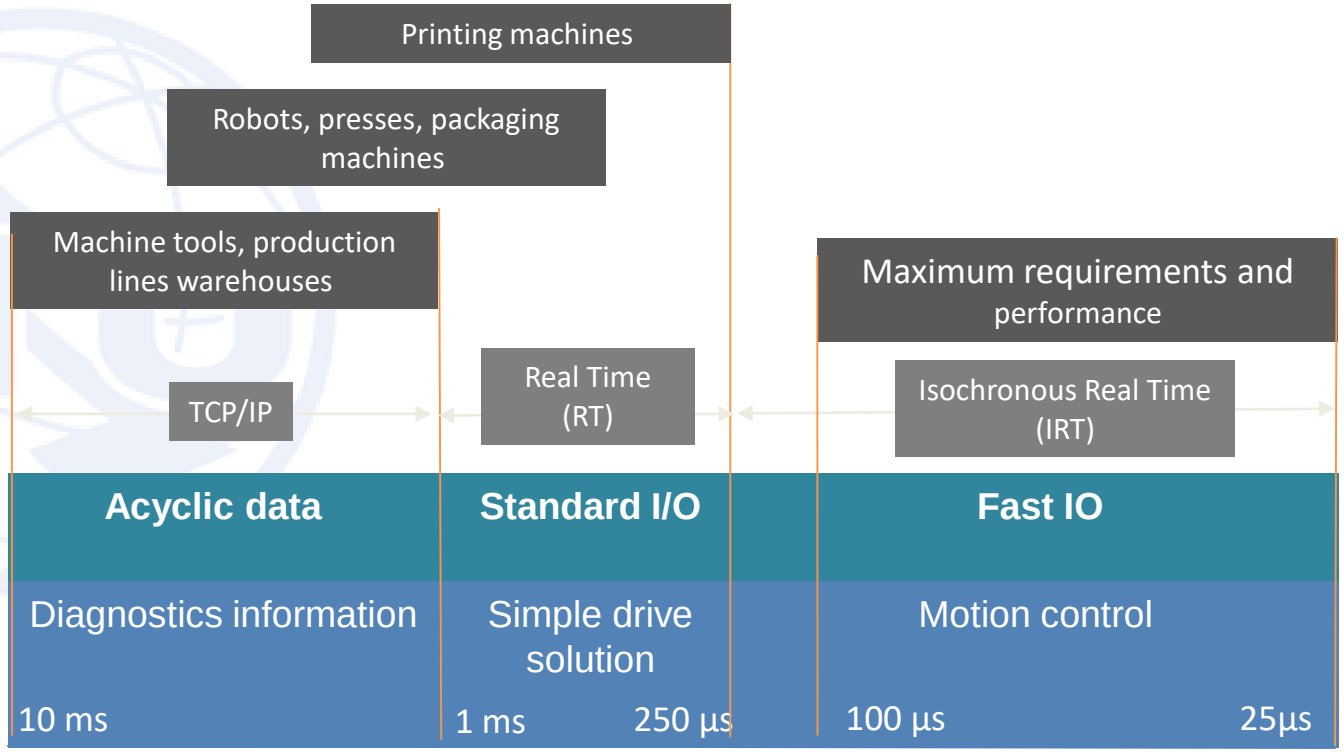
4K/8K HD		VR/AR		Hologram
15 ms~35 ms	delay	5 ms~7 ms	delay	Submillisecond

Synchronization of parallel streams

4K/8K HD		VR/AR		Hologram
Audio/Video(2)	streams	Multiple tiles (12)	streams	~thousands (view-angles)

Precise Latency and Fast Response in Automation and Control





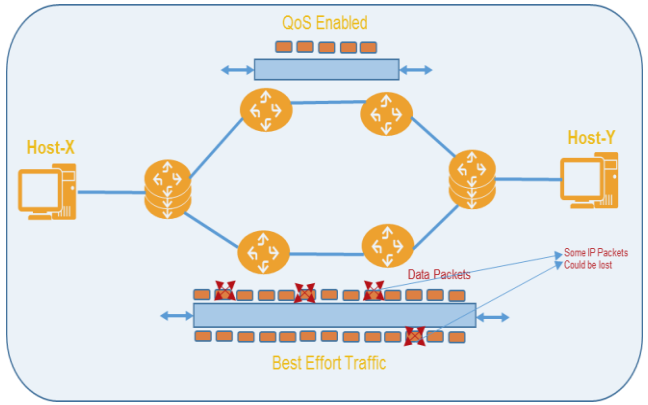
High-Precision Latency in Industrial Internet

Low Latency for Machine Control

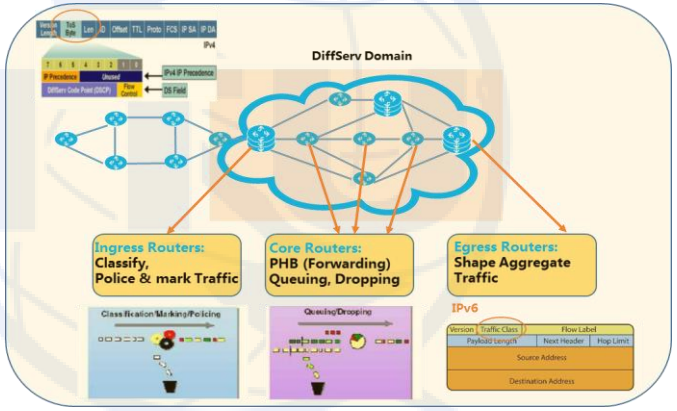
Source: James Coleman (Intel) TSNA'15 - Processor and OS Tuning for Event Response and Time Sensitive Systems.pdf

What Services does the Current Internet Provide at the Infrastructure Level?

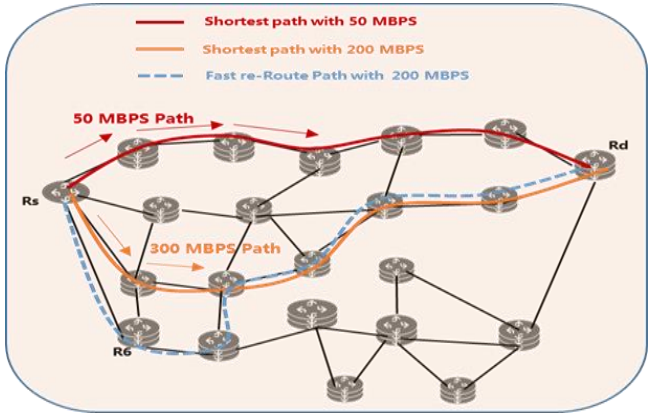
Best Effort



Differentiated Services



Traffic Engineering



- ✓ Differentiates Classes of Service
- ✓ Guarantees Bandwidth

- ✗ Fails to provide throughput guarantees
- ✗ Fails to provide guarantees of maximum latency (in-time)
- ✗ Fails to provide guarantees of precise latency (on-time)

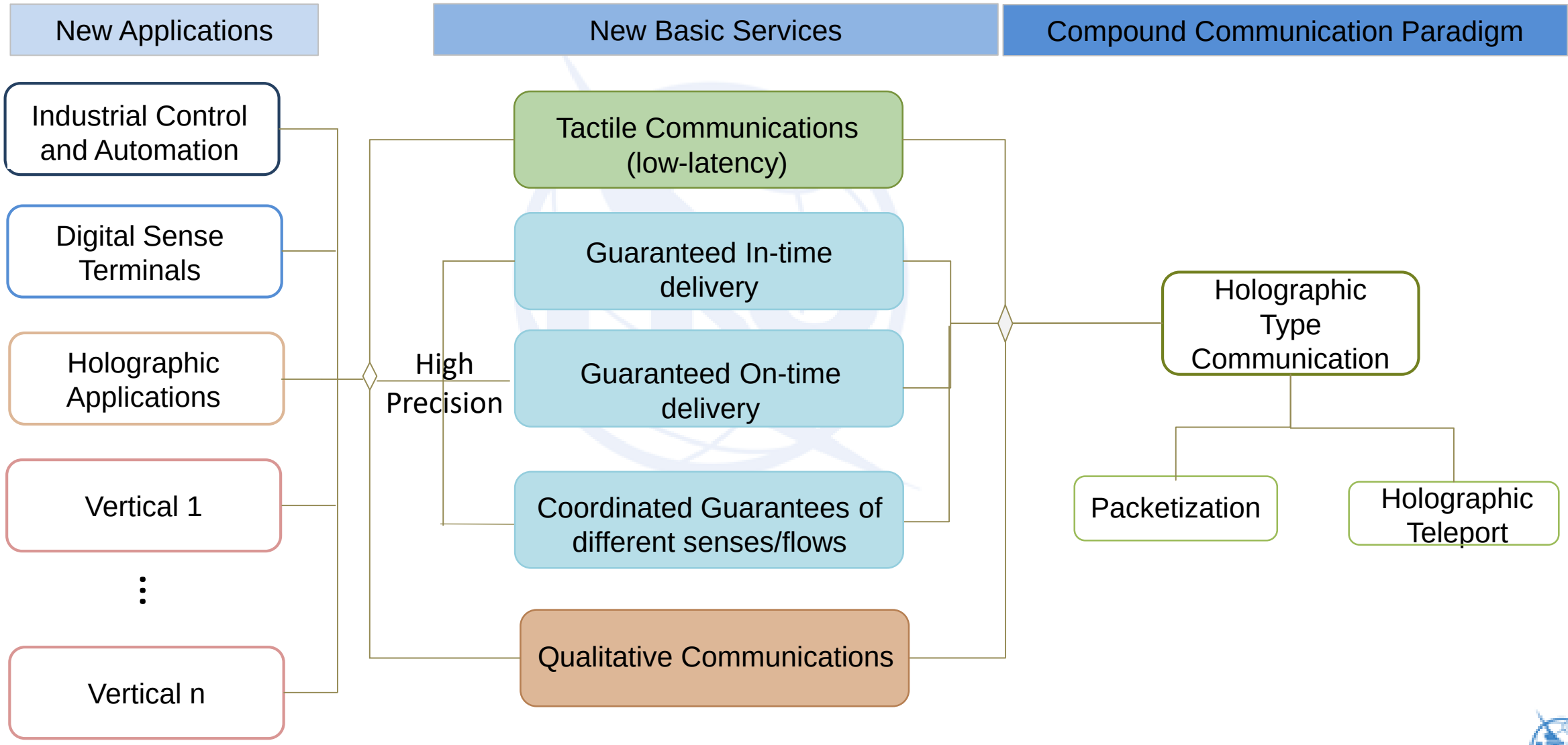
What can we infer from the TCP Throughput Law?

$$\text{TCP Throughput} \leq \min\left(BW, \frac{\text{WindowSize}}{RTT}, \frac{MSS}{RTT} \times \frac{C}{\sqrt{\rho}}\right)$$

- The delay is subject to the speed of light, and it simply can't be as low as we wish
- The throughput is subject to many factors, and it simply can't be as high as we wish
- Example: Assume that you have 1 packet lost every 10,000 packets and you want to have a throughput of 12Gbps, the delay will be 114 us. Can you have it in the Internet?

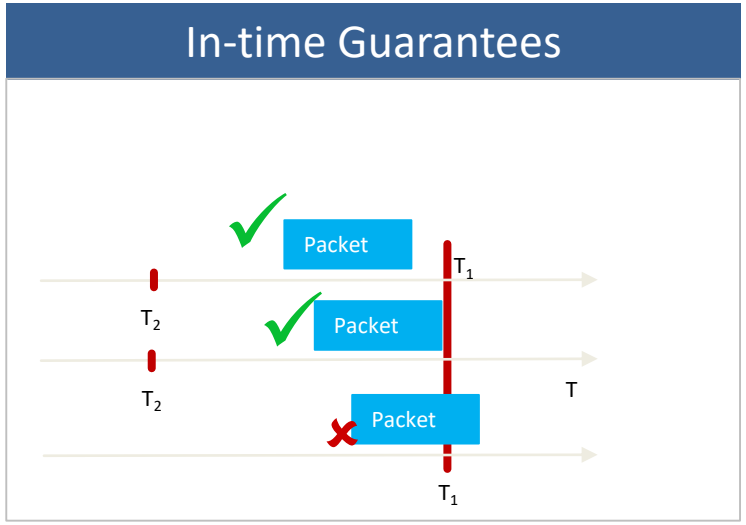
Lost\delay(us)	11	25	36	80	114	255	360
0.00001	390670.011	171894.805	119371.39	53717.13	37696.23	16852.43	**11937.1**
0.00002	276245.414	121547.982	84408.321	37983.74	26655.26	**11916.5**	8440.832
0.0001	123540.705	54357.9102	37748.549	16986.85	**11920.6**	5329.207	3774.855
0.0002	87356.4702	38436.8469	26692.255	**12011.5**	8429.133	3768.318	2669.225
0.001	39067.0011	17189.4805	**11937.14**	5371.713	3769.623	1685.243	1193.714
0.002	27624.5414	**12154.8**	8440.8321	3798.374	2665.526	1191.647	844.0832
0.01	**12354.07**	5435.79102	3774.8549	1698.685	1192.059	532.9207	377.4855

New Communication Paradigms for Emerging Applications



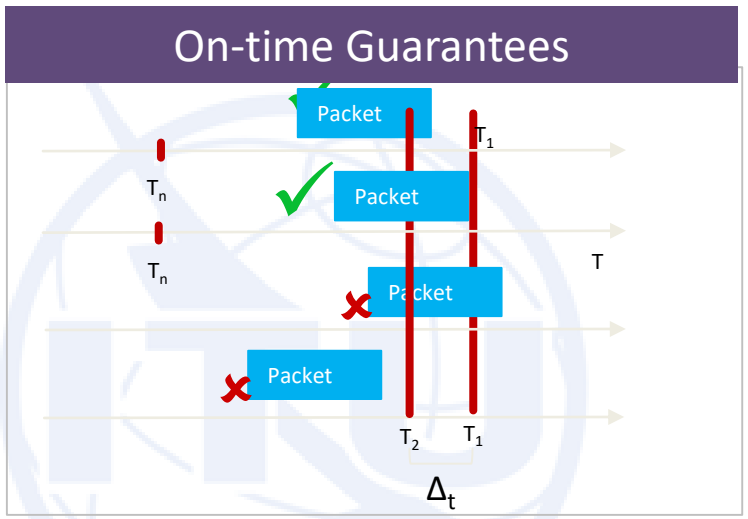
High-Precision Communications

In-time Guarantees



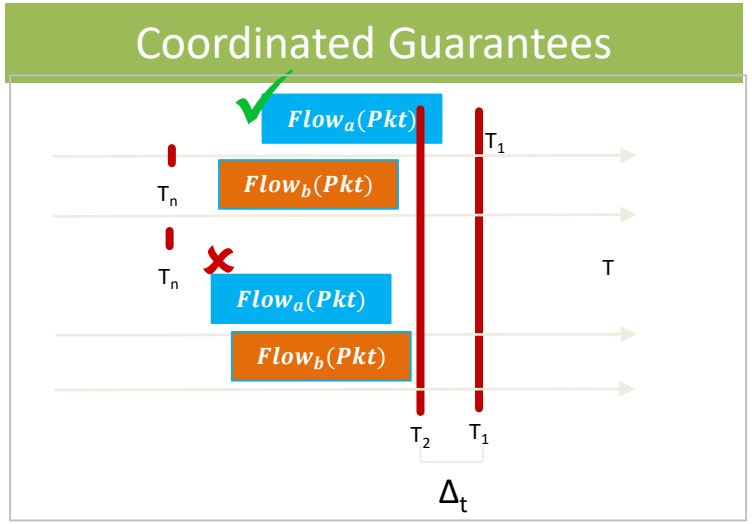
Bounded Latencies: Deliver on or before specified time. Bursts are possible

On-time Guarantees



Bounded Time Interval (Δ_t may be 0): Deliver within specified and generally small arrival variance

Coordinated Guarantees



Packets of two or more flows and streams arrive in a coordinated in-time/or-time guaranteed way

Coordinated G

On-time G

In-time G

High Precision Communications

Latency Precision Attributes

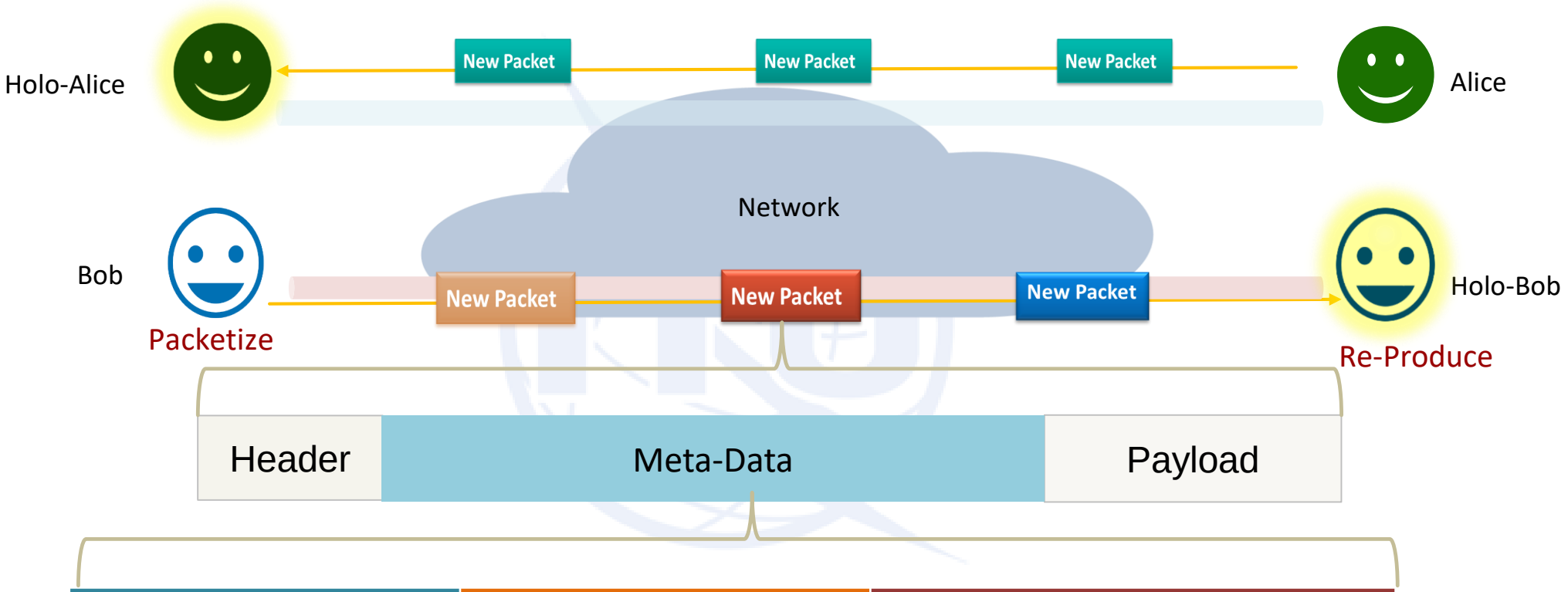
Cause for Delays: Transmission, Propagation, Processing and Queuing

Adaptiveness: to congestion and inter-related flows

Precise measures: Rate of flow, extremely low latencies for critical events such as accident avoidance

Delay variation : Jitter may need to be near zero or extremely low for critical events such as industrial control

Elements of Holographic Packetization

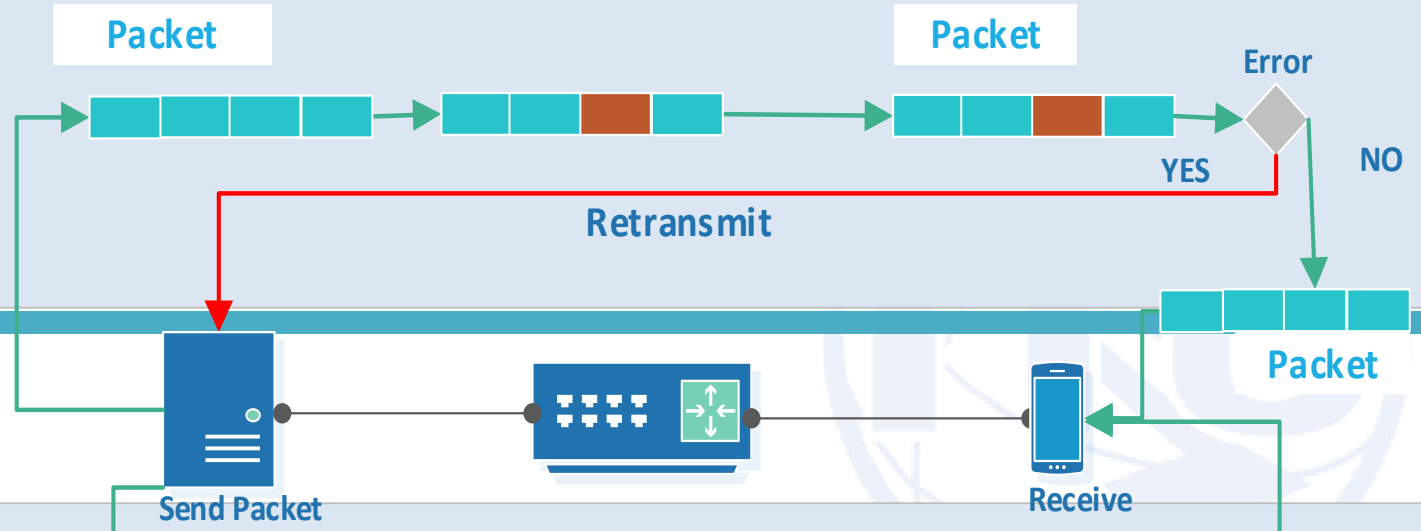


Entropy	Multi-Sense	Action
➢ Binary ➢ Stair-Case ➢ User Defined	➢ Sight ➢ Hearing ➢ Smell ➢ Taste ➢ Touch	➢ Service Guided ➢ Conditional Actions ➢ Signaling Actions ➢ In-Network Computing Actions

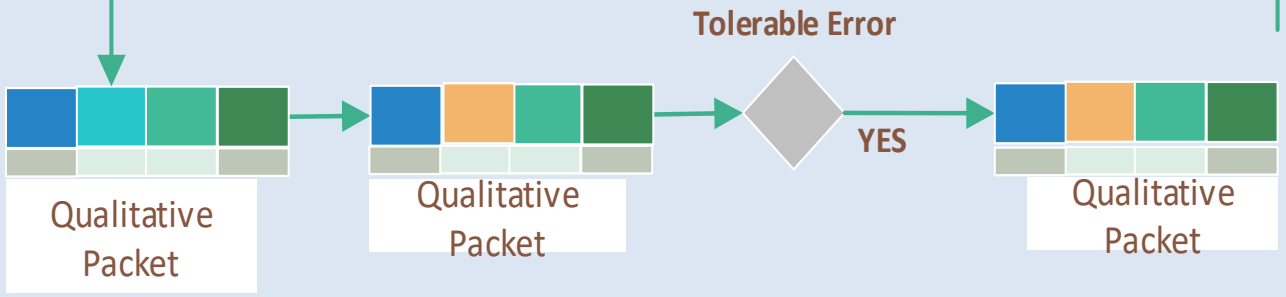
Qualitative Communication Services

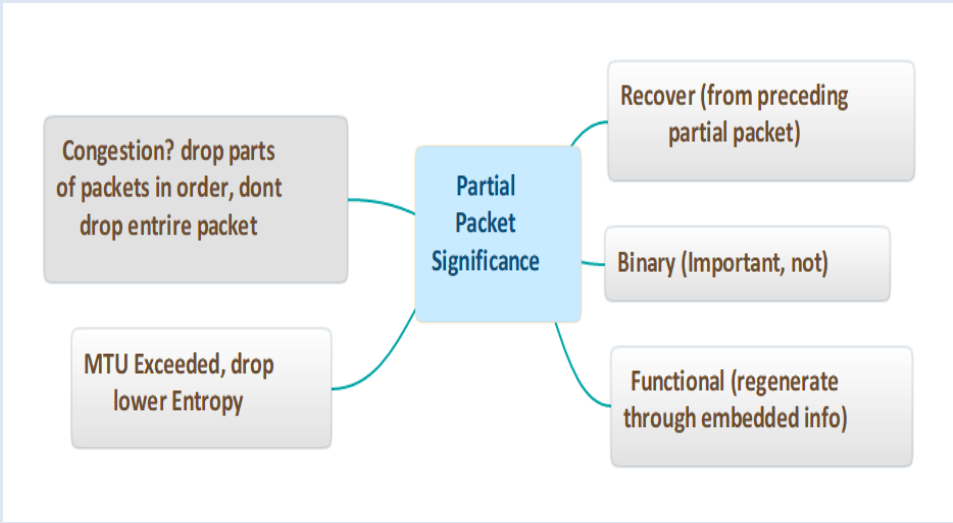
The Current Way: **Quantitative Network Aspects**

- Information packetized in stream of bytes
  - with equal significance
  - CRC over entire payload
- Retransmissions get too expensive
  - Hard to meet high throughput constraints
  - Latency increases



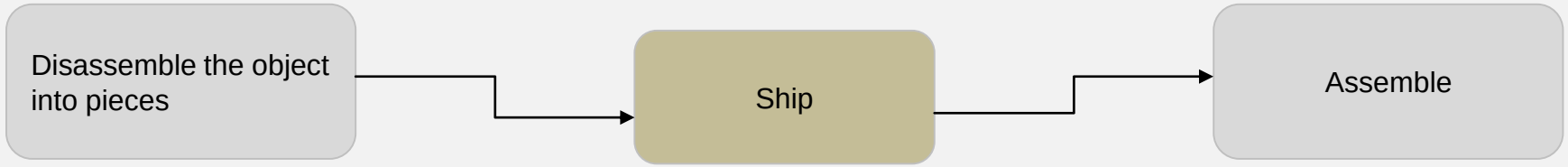
New Way: Qualitative Communication Services



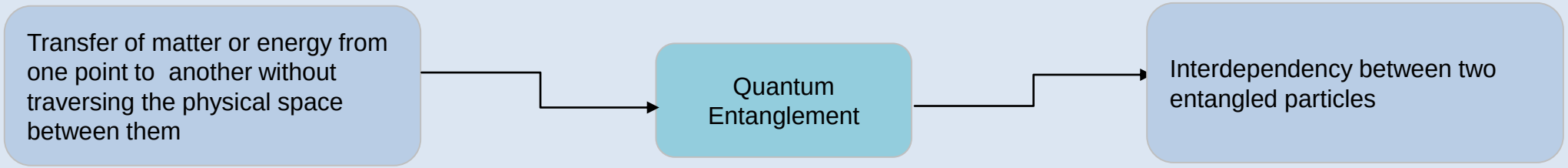


Holographic Teleport – in the context of communications

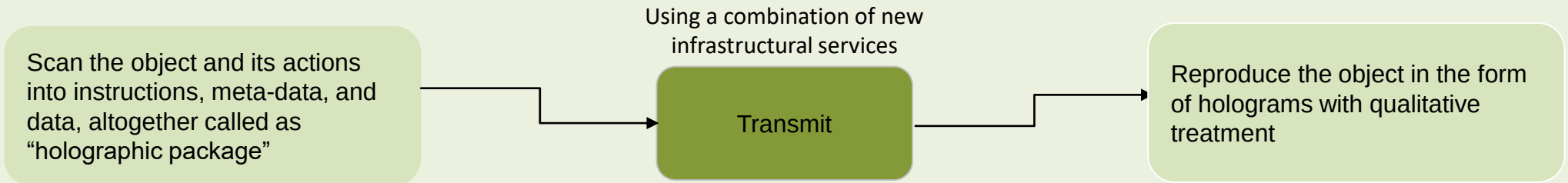
Classical Teleport



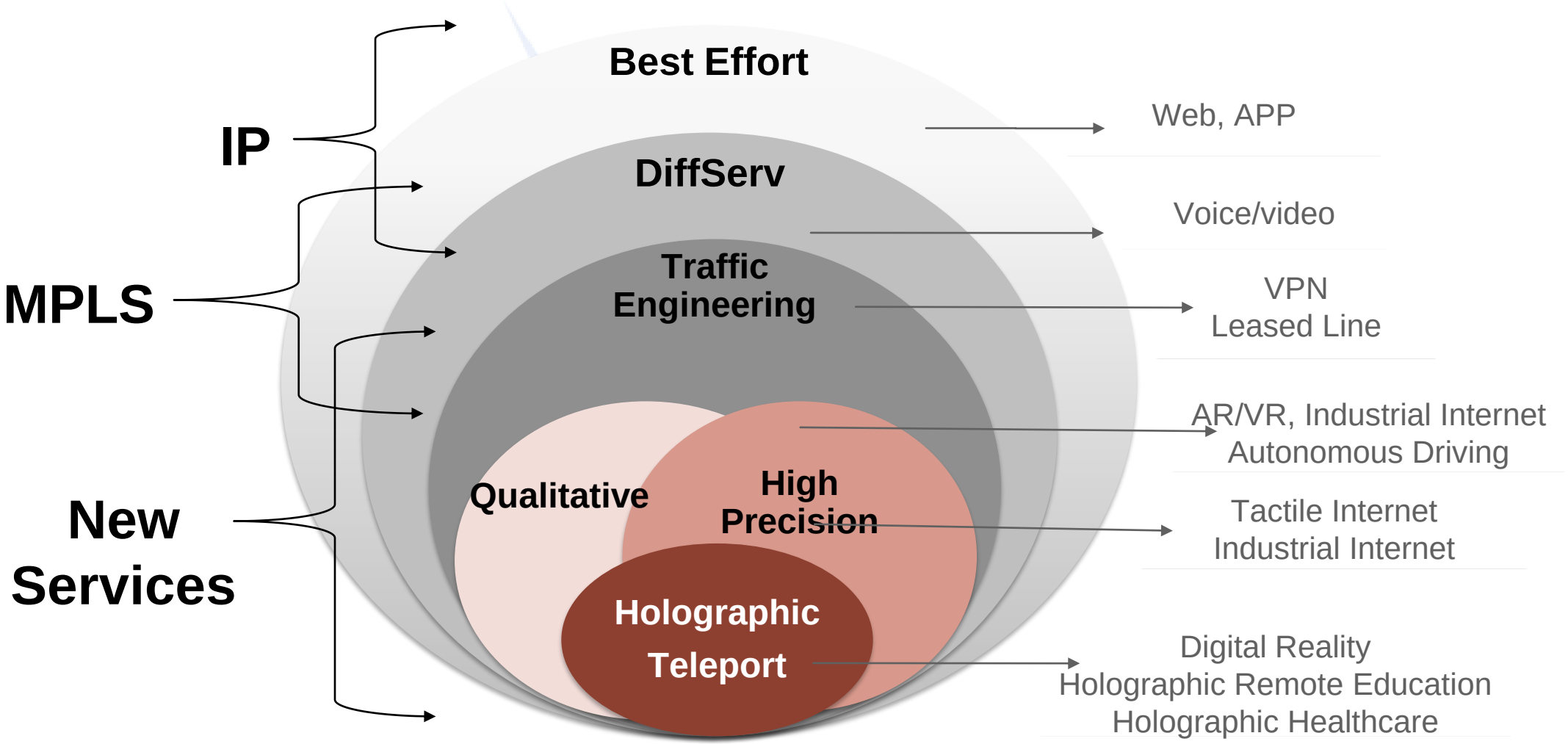
Quantum Teleport



Holographic Teleport

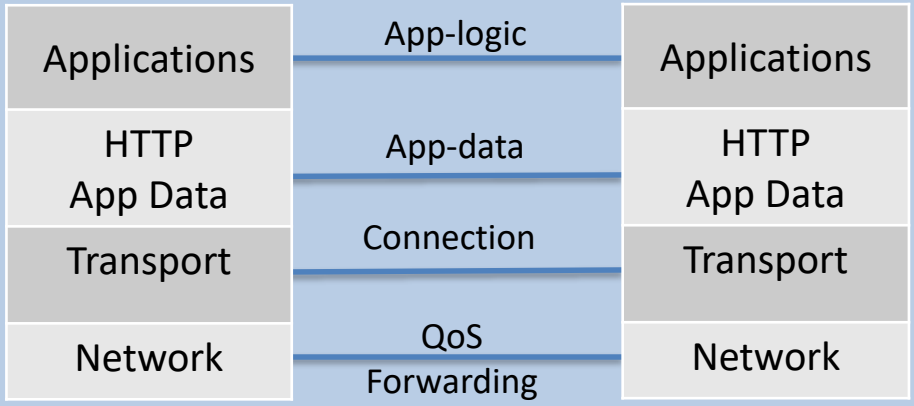


A Taxonomy of Services on the Infrastructural Level



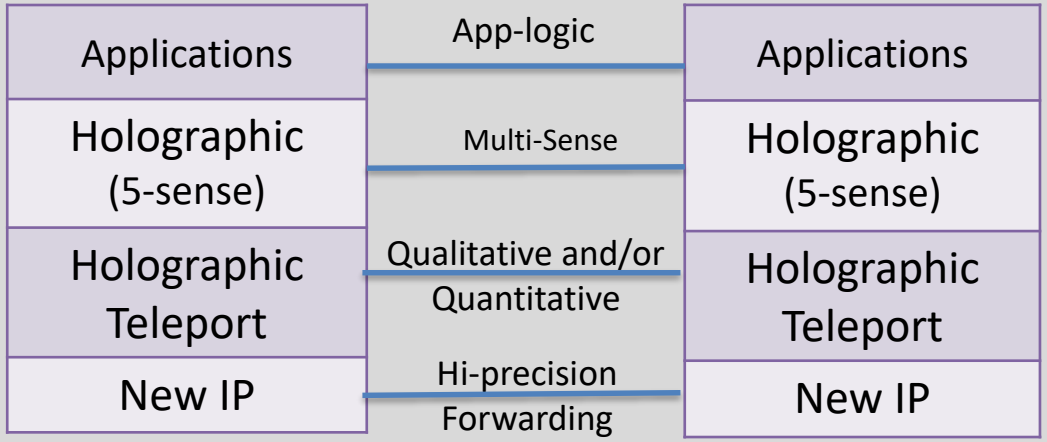
New Concepts for Future Communications

Today's Communications



Transport	An end-to-end mechanism for flow control and reliability
Datagram	A self-contained hop-by-hop routable packet in packet switched networks

Future Communications



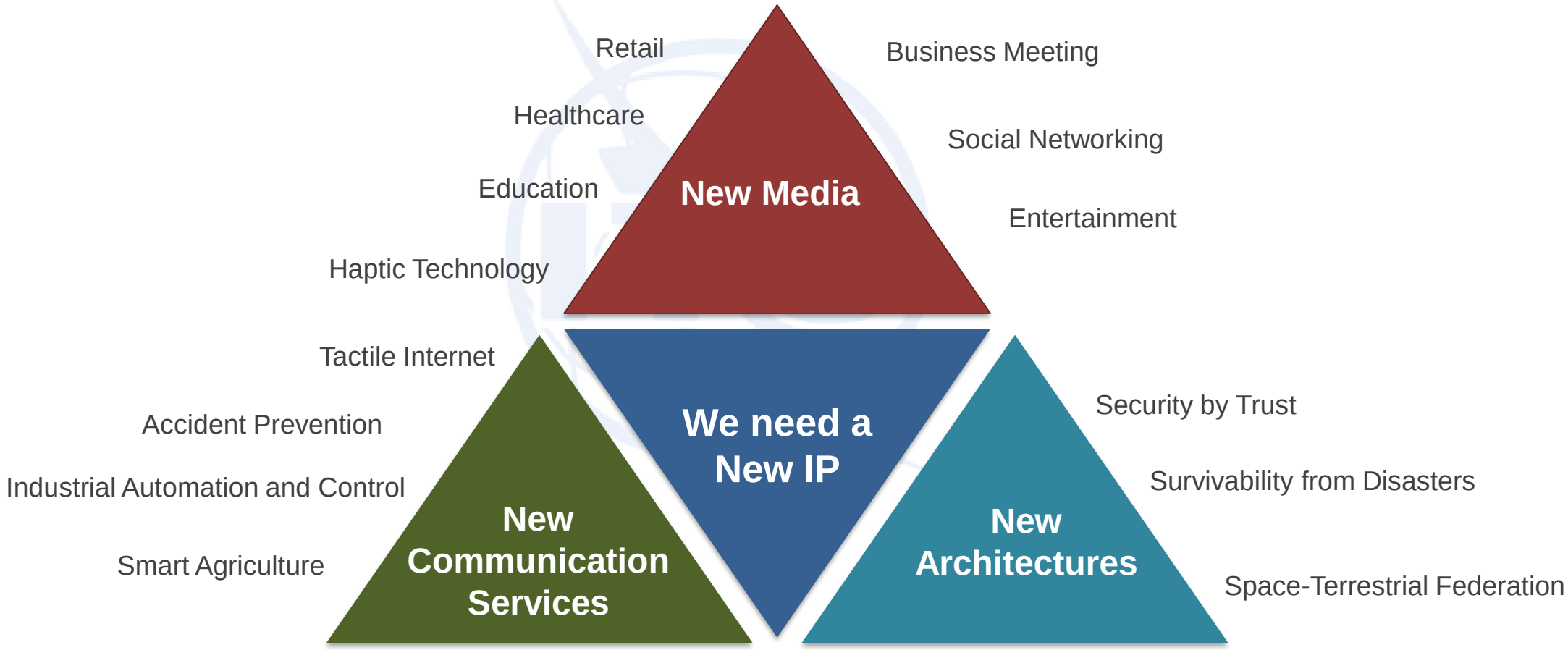
Hologram	New attributes for senses and parallaxes are added
Teleport	A combination of new communication services for holographic applications.
New IP	A new network protocol facilitating new communications services

Basic Challenges and Requirements for Network 2030

- Data Rate (>1Tbps)
- Tactile Communications (extreme low latency)
- In-Time Guaranteed Communications
- On-Time Guaranteed Communications
- Coordinated Guarantee of Flows and Streams
- Qualitative Communication Services
- Digital Senses and Digital Reality
- Holographic Teleport
- Trustability
- Some more..

Network 2030 will enable the New Internet

Holographic Society



Next wave of the Internet Innovations

Trustable and Confident

Q&A

Thank You!