# Networks at the Speed of Light
## pave the way for the tactile internet

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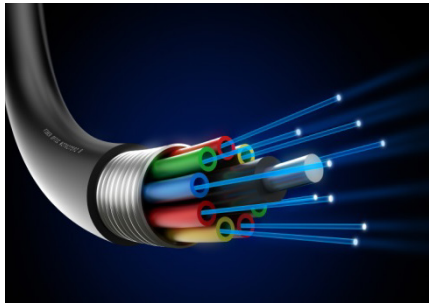
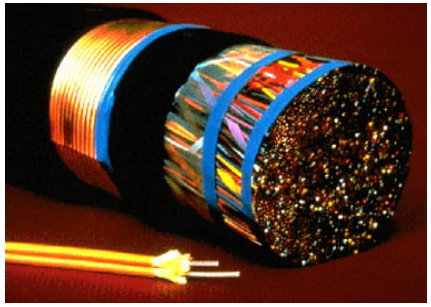
# Networks at the Speed of Light

## We have no Warp like Star Trek- We cannot go faster

In vacuum (or air) the speed of light is about 300.000 km/sec. In one millisecond light travels about 300 km in vacuum.



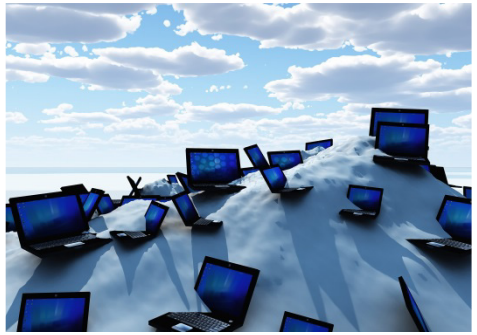
In a fiber the speed of light is about 200.000 km/sec. In one millisecond light travels about 200 km in fibers. *Research: hollow fibers which allow for 97% speed of light!*



Similar, in cooper signals (not electrons) travel with about about 200.000 km/sec.

# Networks at the Speed of Light

## Networks must transfer Data faster and faster



### Fast browsing requires more than just bandwidth

Today, an average web browser session has to deal with multiple TCP connections to different resources, without being able to load everything in parallel. Typically, the response time should be less than 50 milliseconds (ms) for each individual TCP/IP connection.

### Video & voice calls are strongly affected by delay

For fluid calls, the mouth to ear delay should be less than 150 ms. In video calls / conferences lip synchronization enters the scene. A skew of less than 20 ms is considered imperceptible. Above 50 ms, viewers will begin to notice the audio/video mismatch

### Cloud-based applications are very delay sensitive

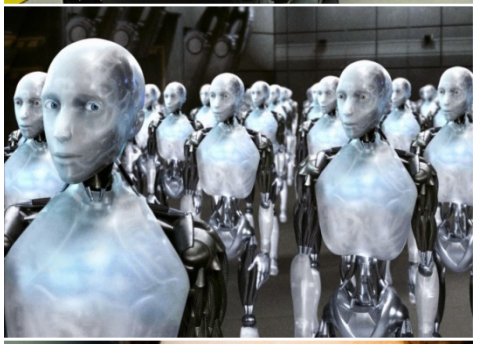
The time difference between a player performing an action and the result of that action appearing on the screen should be less than 100 ms. In some fast action games, latency in excess of 70 or 80 ms may be unacceptable.

# Networks at the Speed of Light

## Some Applications require Responses in the Milliseconds

### Remote controlled robotic surgery

Earliest remote surgery conducted 7 Sept. 2001 between New York and Strasbourg over dedicated fiber for guaranteed connectivity and minimal lag. Working with force feedback handles and a mean lag of 155 ms required a lot of training. Aim is latency well below 10 ms.



### Collective robotic mind in the cloud

Provide cloud scale computation at extremely low latency to bring the efficiency of robotic assistance to manufacturing, health care, and research. Would need < 10ms latencies for sensorial actions that require dynamic reactions. Typically 1ms results in a mm.

### Real time memory for the disabled

Collect, store and process real time audio and visual impressions. Deliver context relevant information real time to assist people with brain injuries or Alzheimer. Give context dependent instructions in real time to remind the disabled to perform necessary actions.

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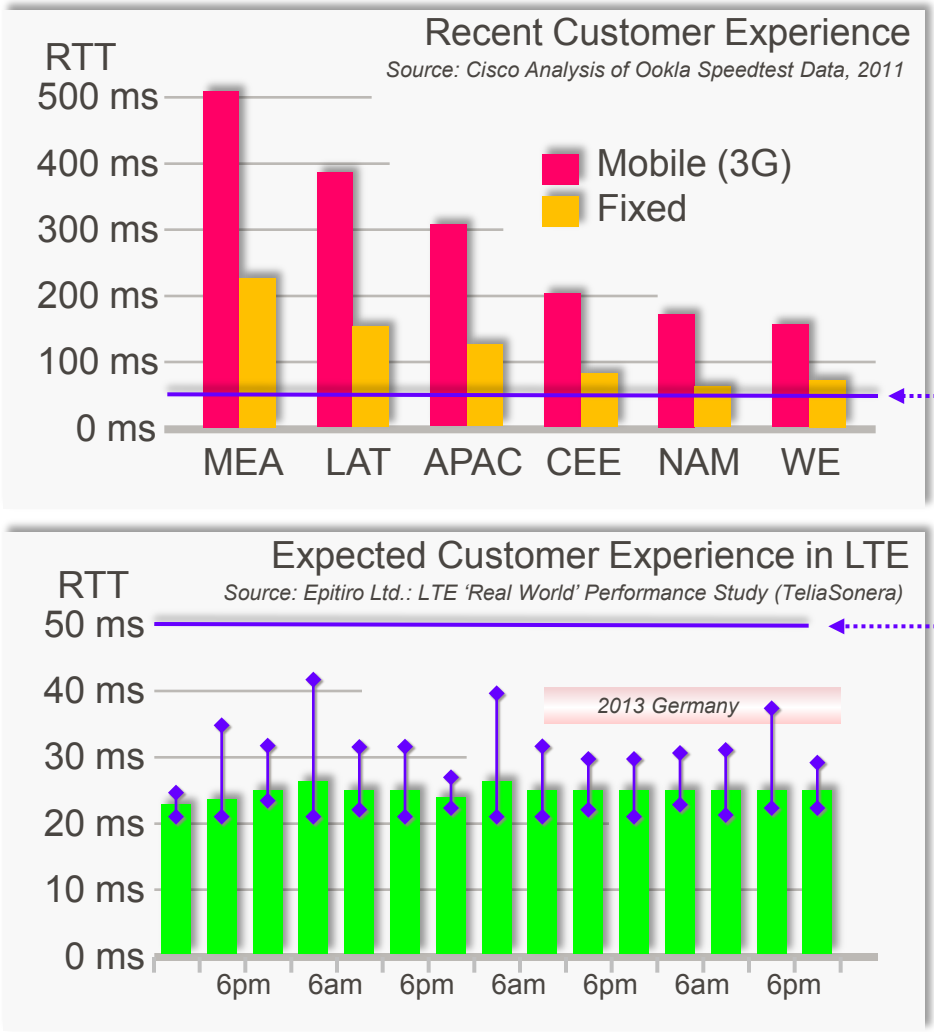
## Our current Internet is not close to support tactile Apps




### DSL Internet RTT - today:

- Germany: ~ 10 msec – 60 msec
- Transatlantic: ~ 150 - 200 msec

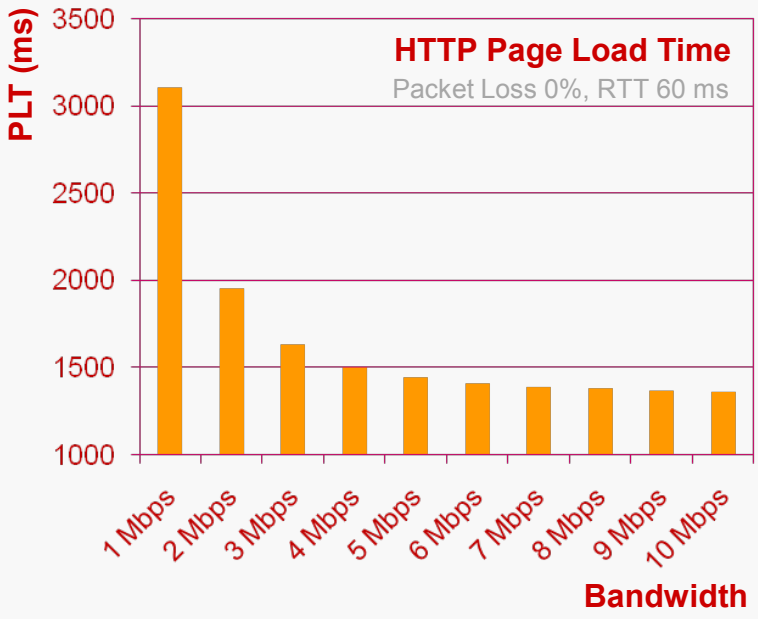
### LTE Internet RTT - today:

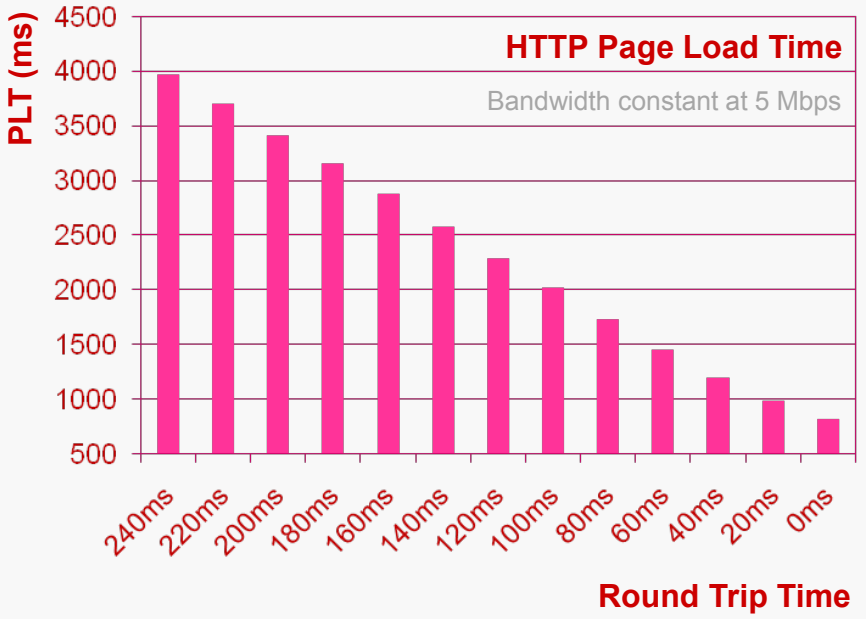
- Germany ~ 35 msec – 40 msec
- Transatlantic: ~ 150 - 200 msec

# Networks at the Speed of Light

## More Bandwidth Doesn't Matter (Much)

### HTTP Page Load Time strongly depends on Round Trip Time (RTT)




### Above 5 Mbps for web page downloads RTT more important than bandwidth

- Internet Today: RTT 50 ms – 250 ms independent on available bandwidth
- Music, videos, other large files utilize bandwidth much better than web pages

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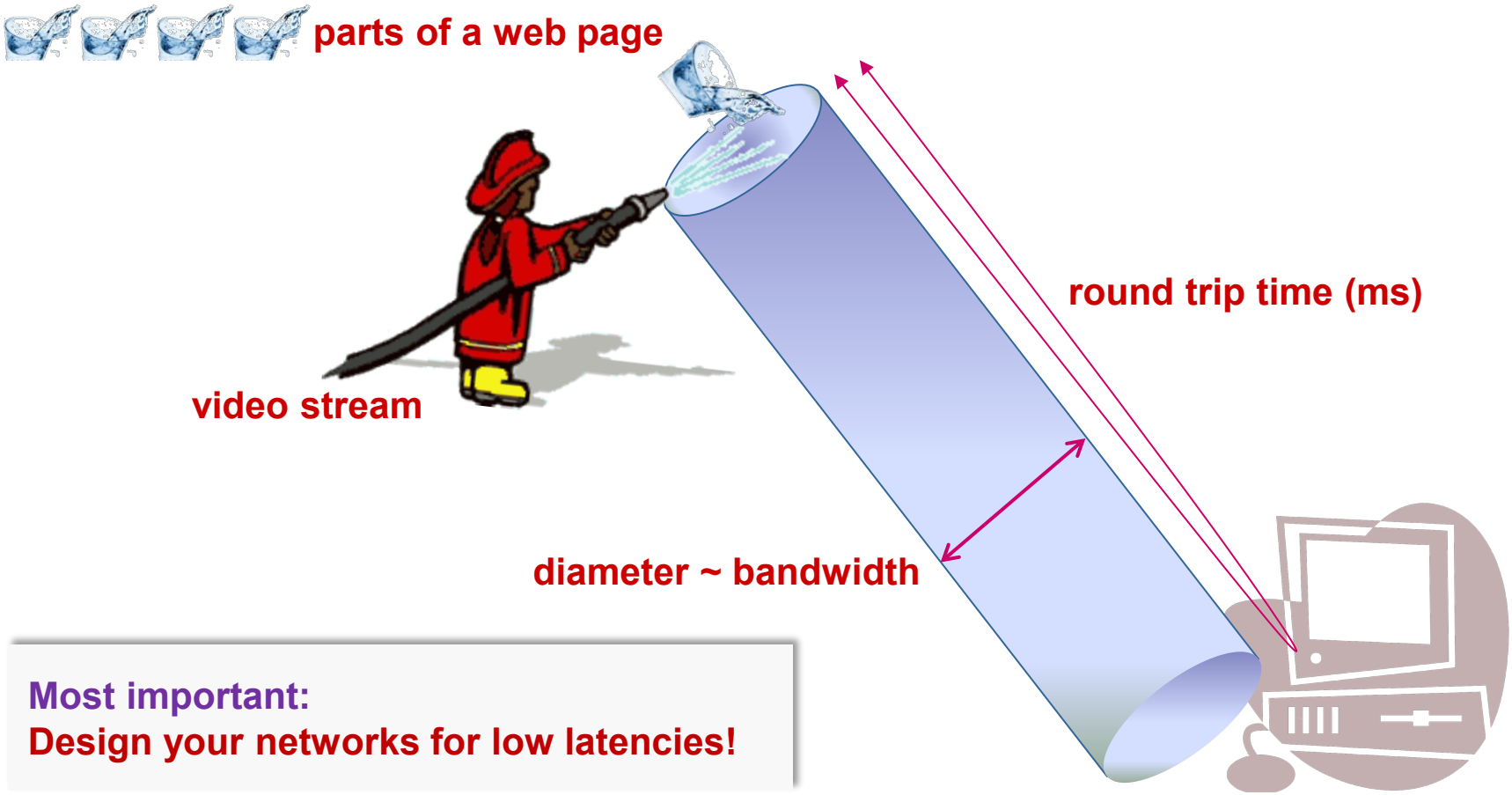
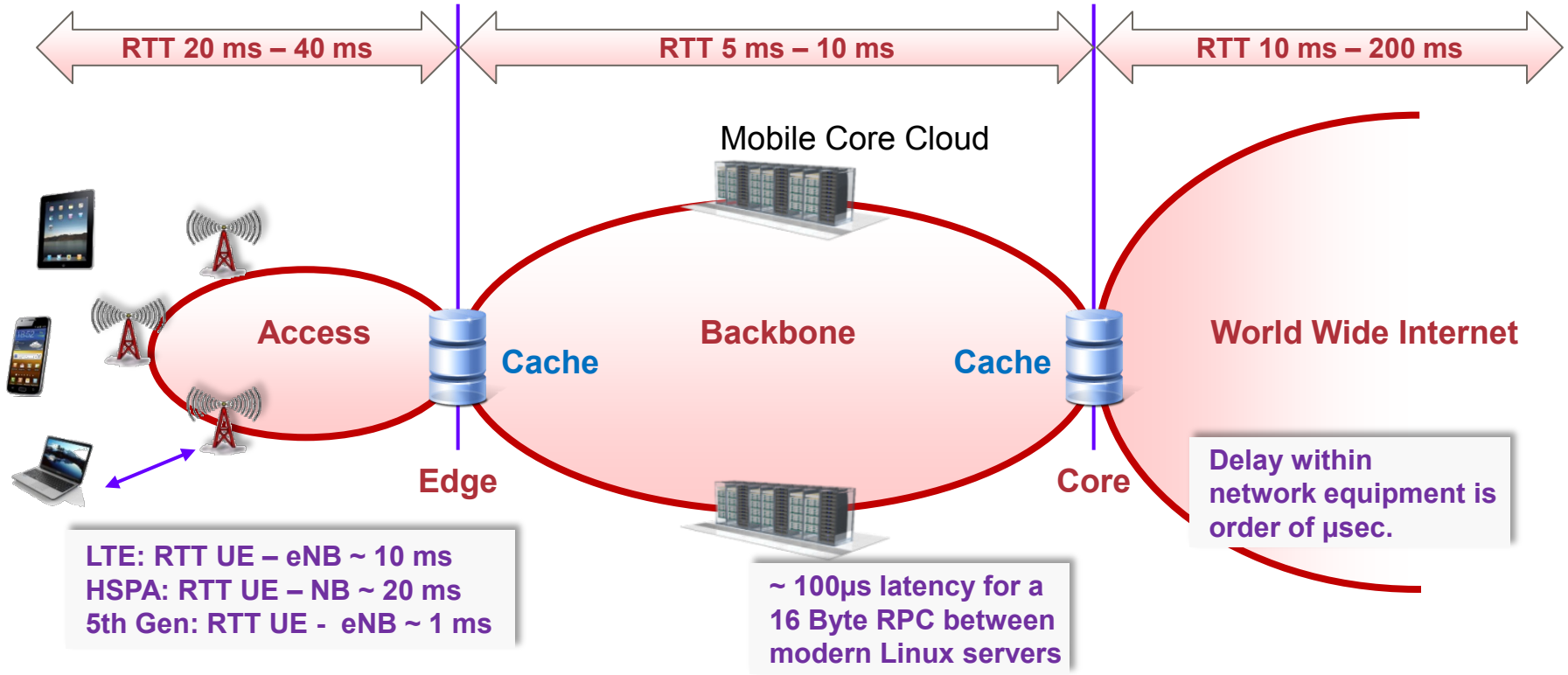
## RTT cannot always be improved by just more Bandwidth




**Most important:**
**Design your networks for low latencies!**

# Networks at the Speed of Light

## Policies control Content Delivery, Caching, Pre-Fetching



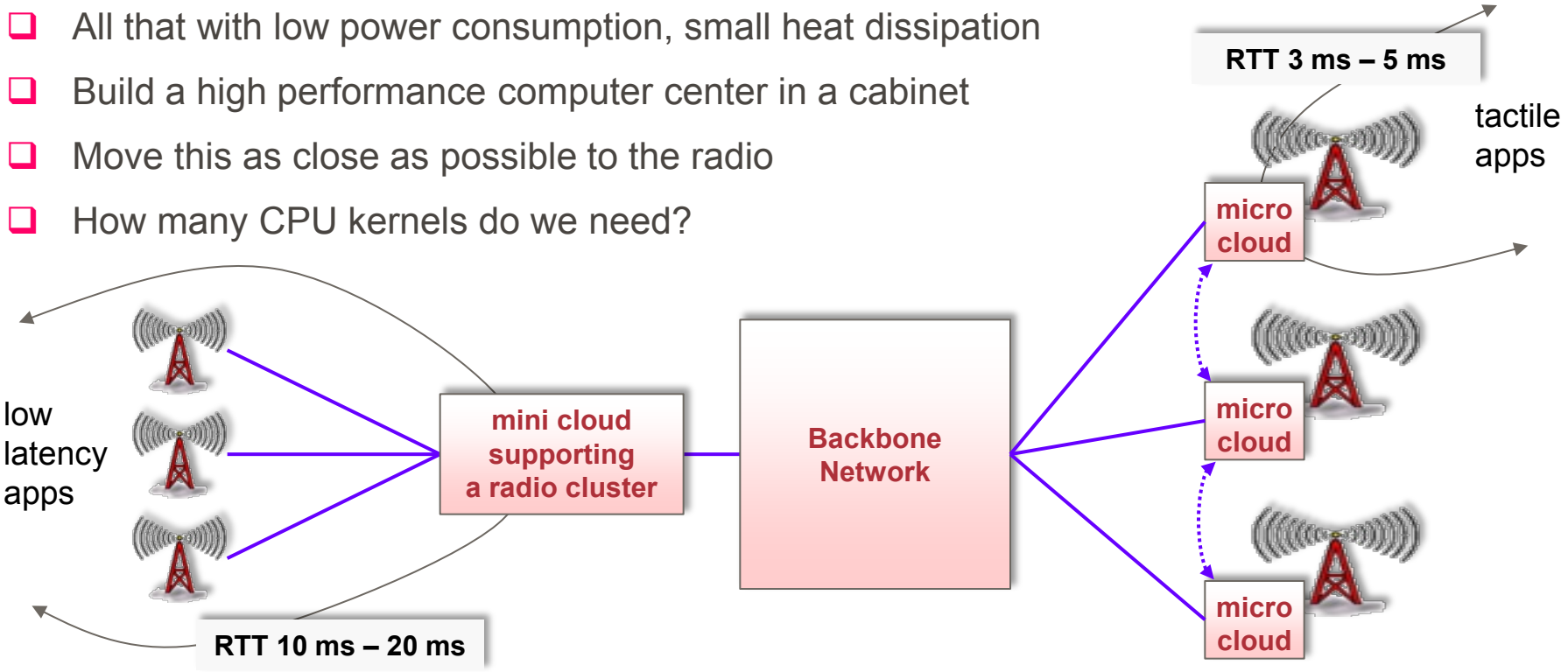

Using caches and by that avoiding some thousand km Internet can potentially improve page load times by some hundred milliseconds

# Networks at the Speed of Light

## Tactile Internet Applications require new Architectures

### Speed of light requires to move tactile application close to the user

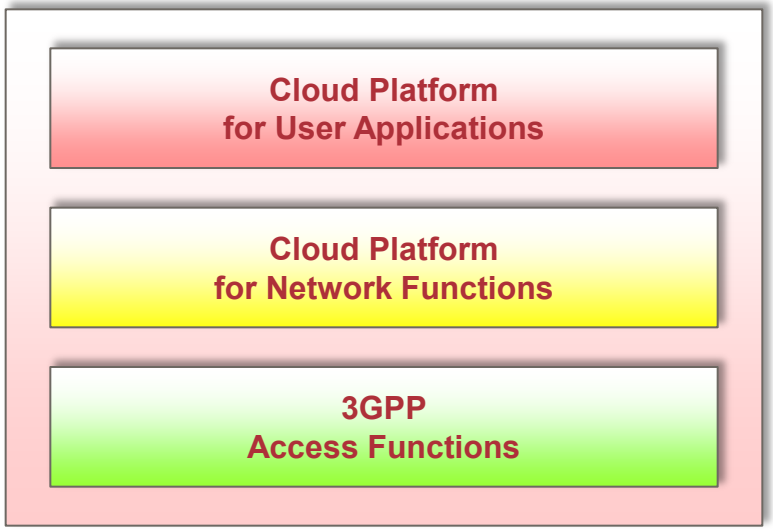
- Invent new silicon architectures allowing massive parallel computing power
- Invent super fast memory with by now unseen high storage density
- All that with low power consumption, small heat dissipation
- Build a high performance computer center in a cabinet
- Move this as close as possible to the radio
- How many CPU kernels do we need?



# Networks at the Speed of Light

## Mini and Micro Cloud Centers in a Box

### Building blocks of a network in a box (mini/micro mobile network cloud)




tactile apps (traffic steering),
low latency apps (gaming)
Web caches etc. ….

Network control functions
policy control, optimizers,
security etc. …

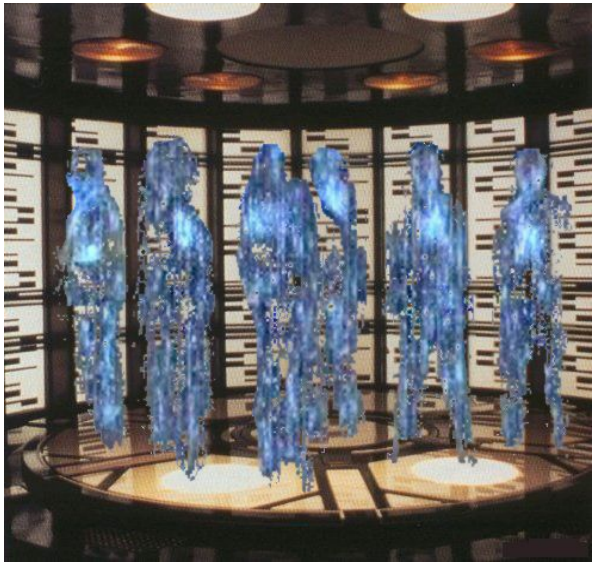
3GPP interfaces to radio
equipment…

Typical cloud paradigm builds on inexpensive commodity computing hardware. But low latency, beyond 4G networks for the next decade 2020 – 2030 will require new high performance silicon for radio and powerful mini/micro clouds to ensure requested computing power and package density in combination with new, more distributed system and network architectures to fight the speed of light limit in todays networks architectures.

# Networks at the Speed of Light

## And beyond – if Physics allows ☹

**And for this kind of mobile networking...**

**we have to wait some more time …**


thank you for listening
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