Cognizant Networks: A Model for Session-based Communications and Adaptive Networking

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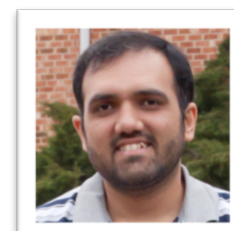


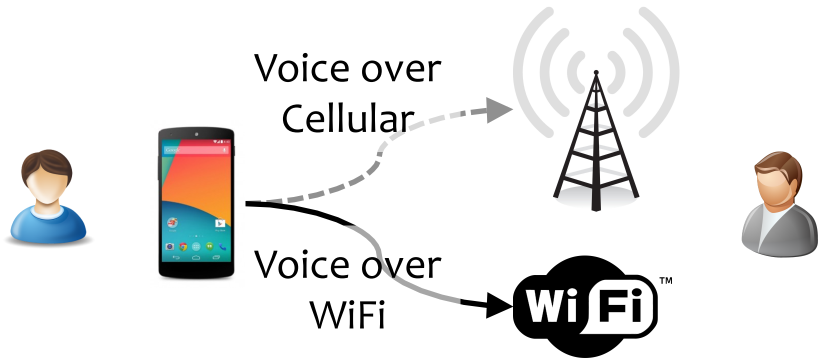
Umar **Kalim**
CS Dept., VT

VirginiaTech
Invent the Future

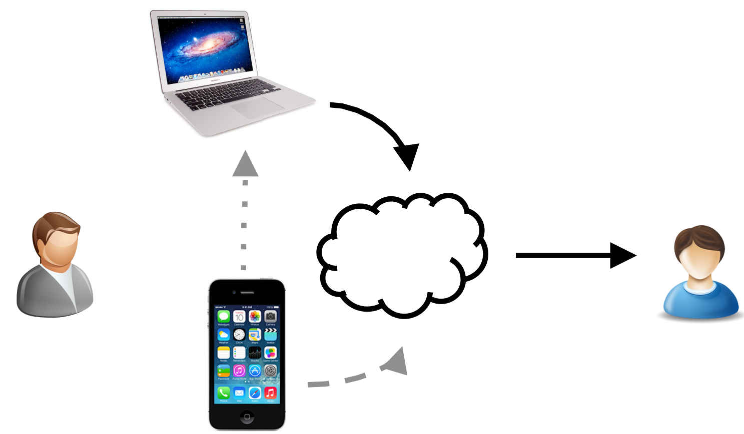
08/21/2015

SyNeRG
synergy.cs.vt.edu

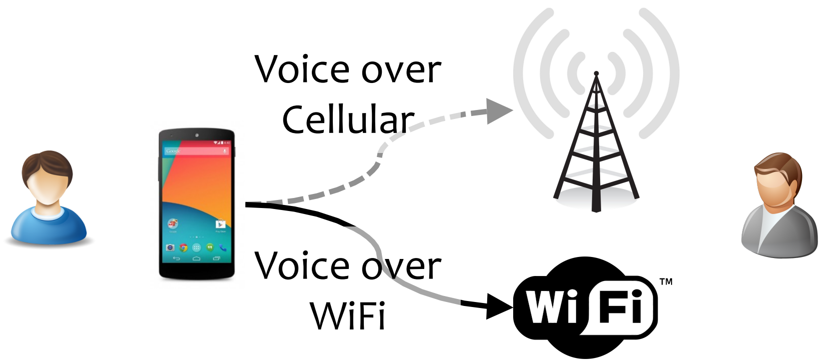
Modern Use Cases



Seamless handoff w/ WiFi calls
(Android OS)



Continue using network
applications with different devices
(Apple Continuity)



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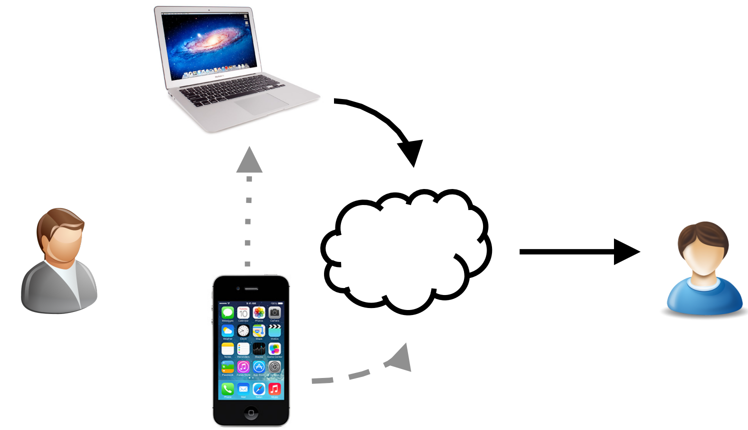

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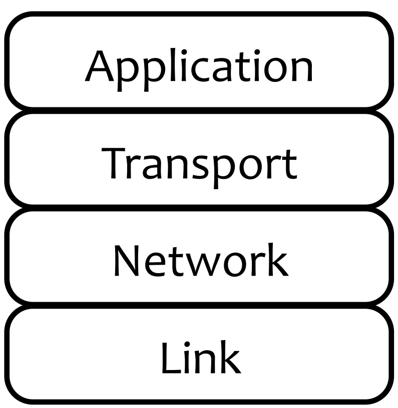
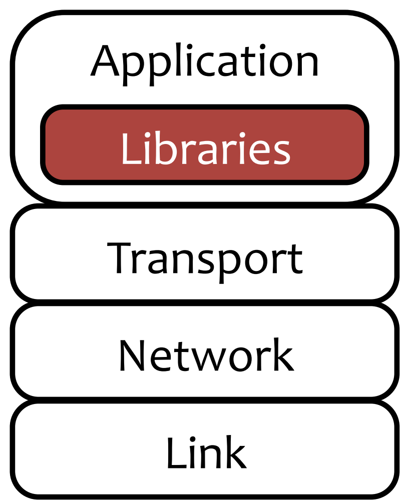
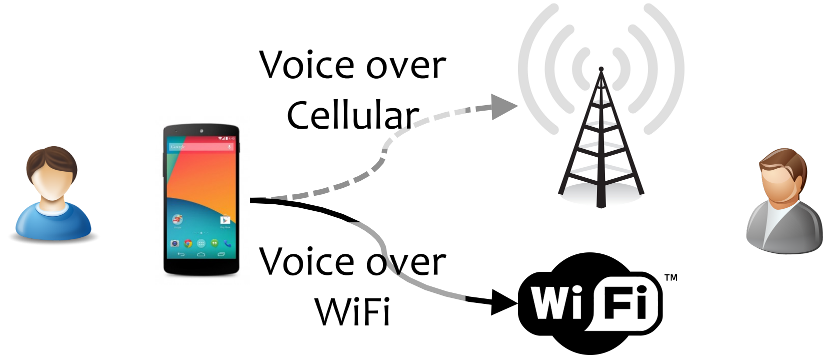


Typical TCP/IP Stack



Modern Stack

Onus is on developers to implement <u>new features</u> as well as <u>support mechanisms</u>



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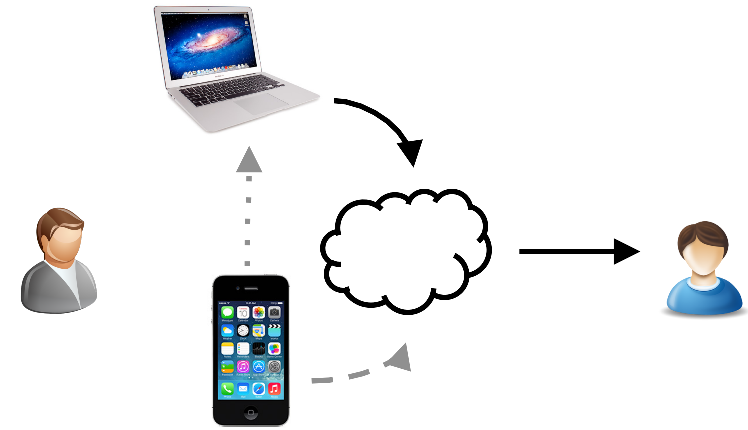

Continue using network
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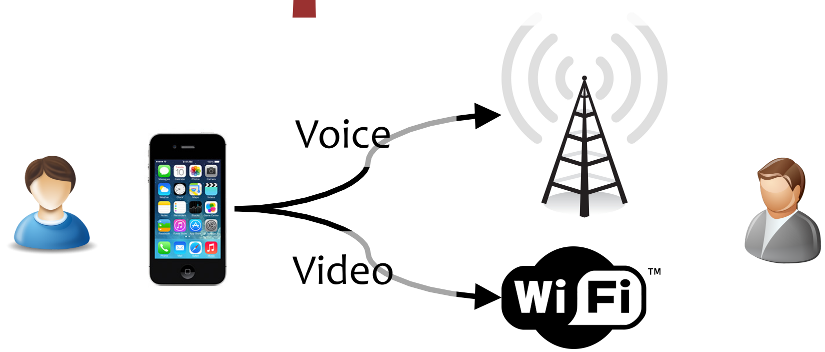
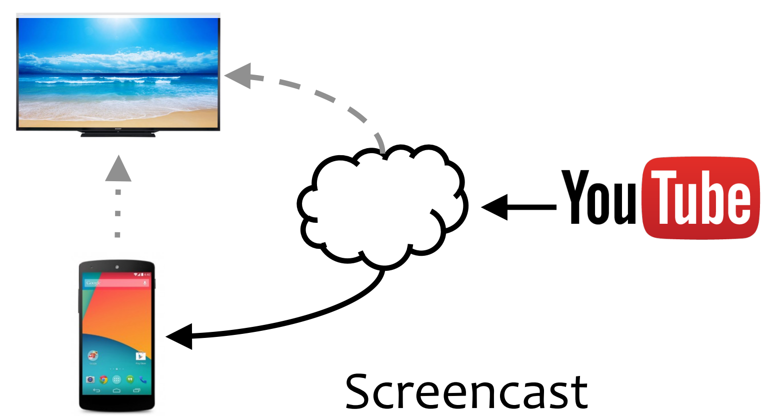
Duplication of effort!



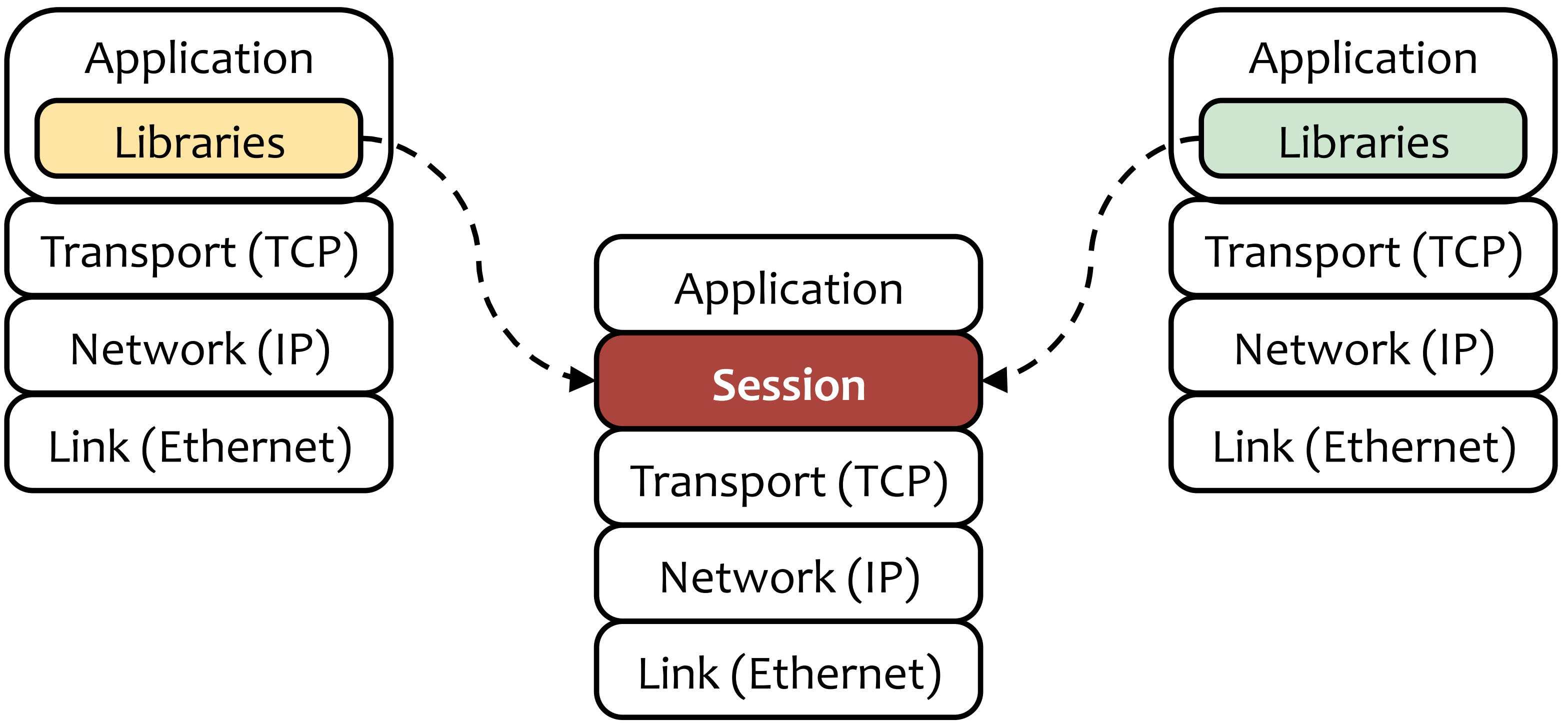
Voice & video over different networks
(Apple Facetime)



Screencast
(Google Chromecast)

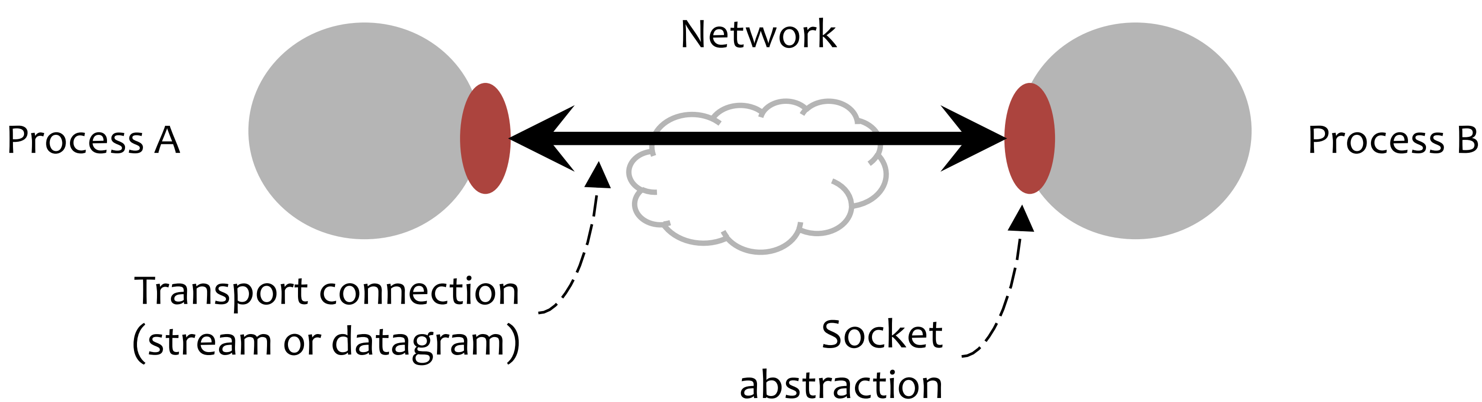
Aspiration

To enable support for modern use cases and future extensions



Challenges of Network Stack Extensibility

- Limitations of TCP (w.r.t modern use cases)
  - Session and transport semantics are coalesced
  - Model assumes two participants
  - Socket abstraction is limiting for modern use
    - Defines an endpoint of communication for a process
    - Label: <srcIP, dest IP, srcPort, destPort>



Limiting Assumptions of TCP Implementations

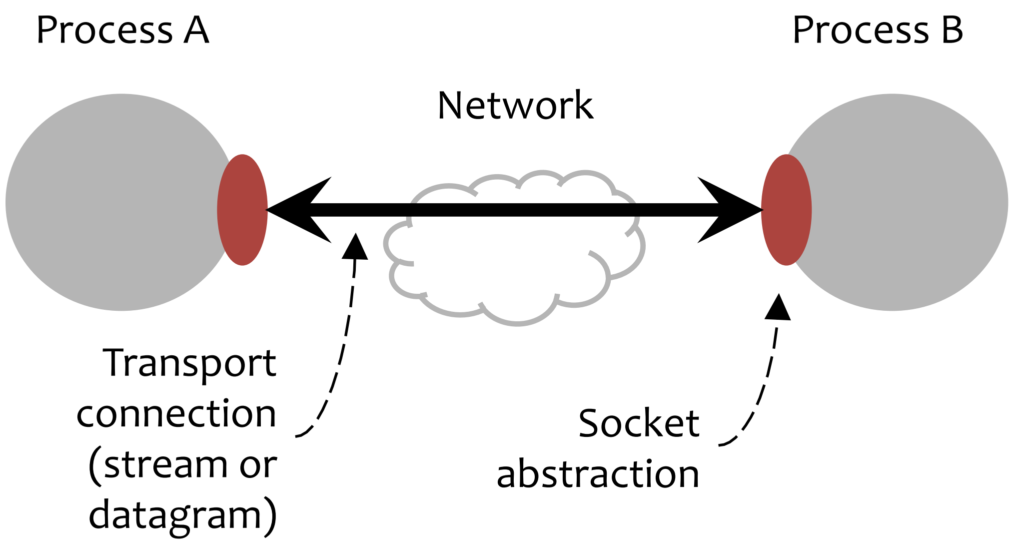
TCP Implementation Assumptions	Challenges
Stream label: socket pair Coupling of transport and network layer	• Naming

Single interface / attachment point
Preclude multiple transports via different networks
	• Flow Abstractions
	  • Multipath TCP
	  • Multihoming
	  • Flow Migration
	  • Hybrid Transport
	• Session Management

Lifetime of IP address assignment greater than lifetime of the connection	• Mobility
Dumb network	• Middleboxes as 1st class citizens
Static configuration	• Cross layer communication • Dynamic stack composition

Research Challenges

Communication Model



Socket defines an endpoint of communication
for a process identified by:
<srcIP, dest IP, srcPort, destPort>

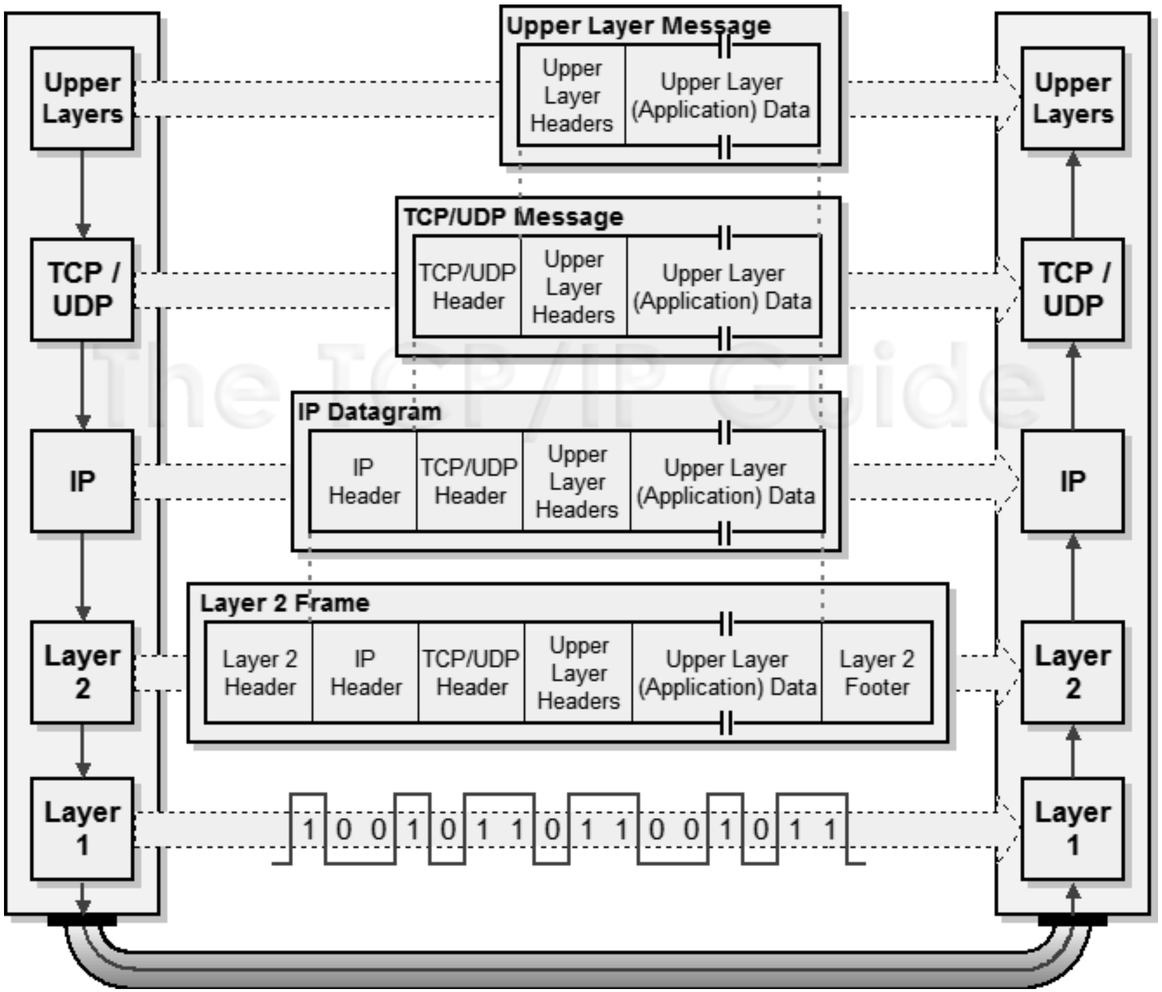
What abstractions do we need to *describe communication* and enable *management*?

How would these abstractions *fit* with existing designs?

How do we *discover*, *describe* and *use* context of communication?

How do we enable *dynamic configuration*?

Research Challenges
Backwards compatibility



How do we extend the network stack such that it allows *interaction with legacy stacks* and *applications*?

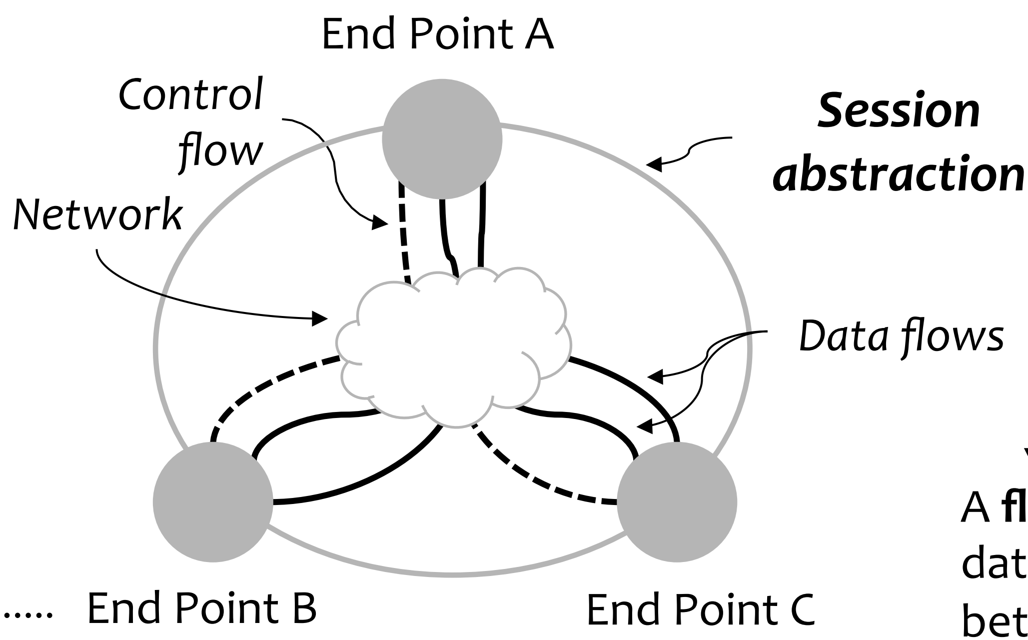
Image source: tcpipguide.com

Problem Statement

How to design, implement and evaluate abstractions that enable extensions to the network stack and allow configuration and reconfiguration of communications?

Session Abstraction

Representation of a conversation between participants in an agreed upon context

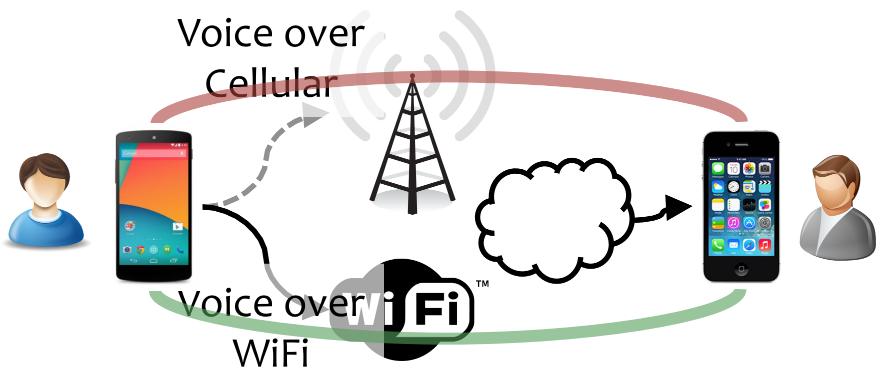


An **end point** is a participant that represents the source and destination of communications

A **flow** represents a data exchange between a set of end points

Session Abstraction

Representation of a conversation between participants in an agreed upon context



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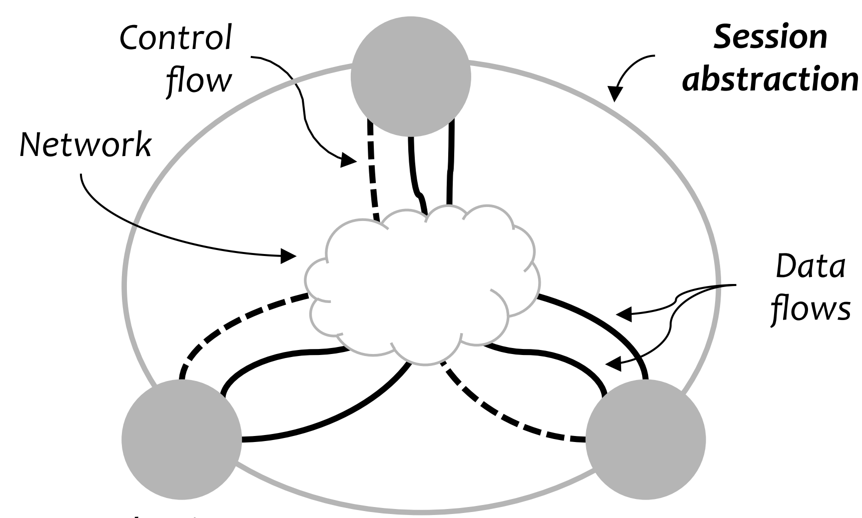
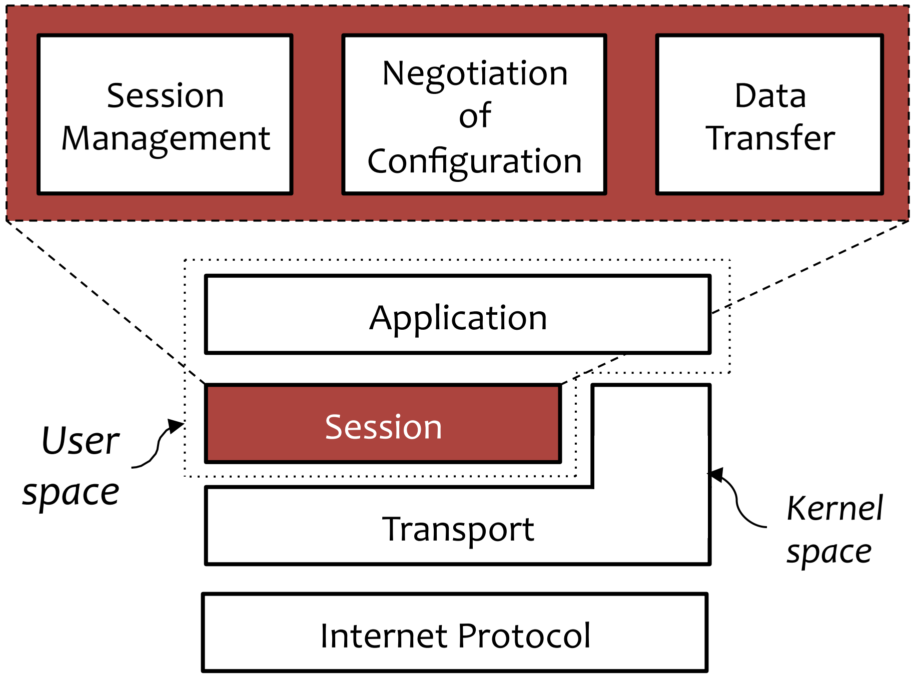


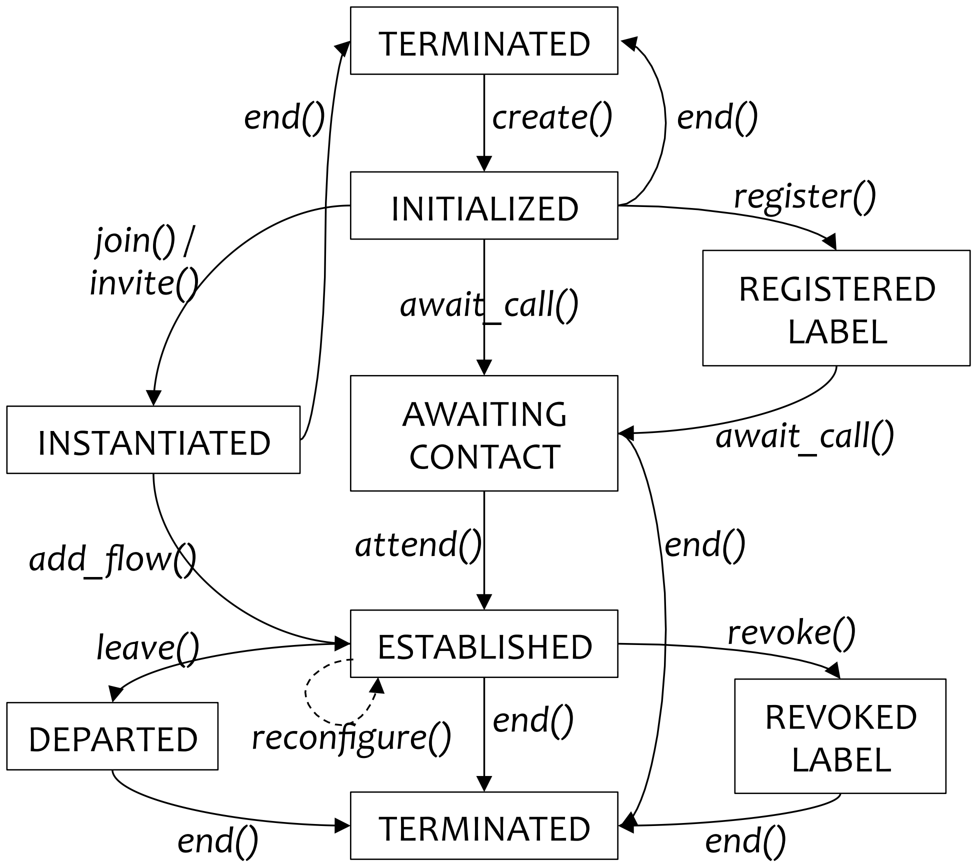
Session Layer in the Network Stack



- Additions to TCP to enable extensibility
  - Ability to accept custom TCP options to be aware of session-layer services
- Session-layer services in user space

Primitives and State Transitions

Session Management | Negotiation of Configuration | Data Transfer



Primitives and State Transitions

Session Management | Negotiation of Configuration | Data Transfer

Session-Related Primitives

create(session)
end(session)

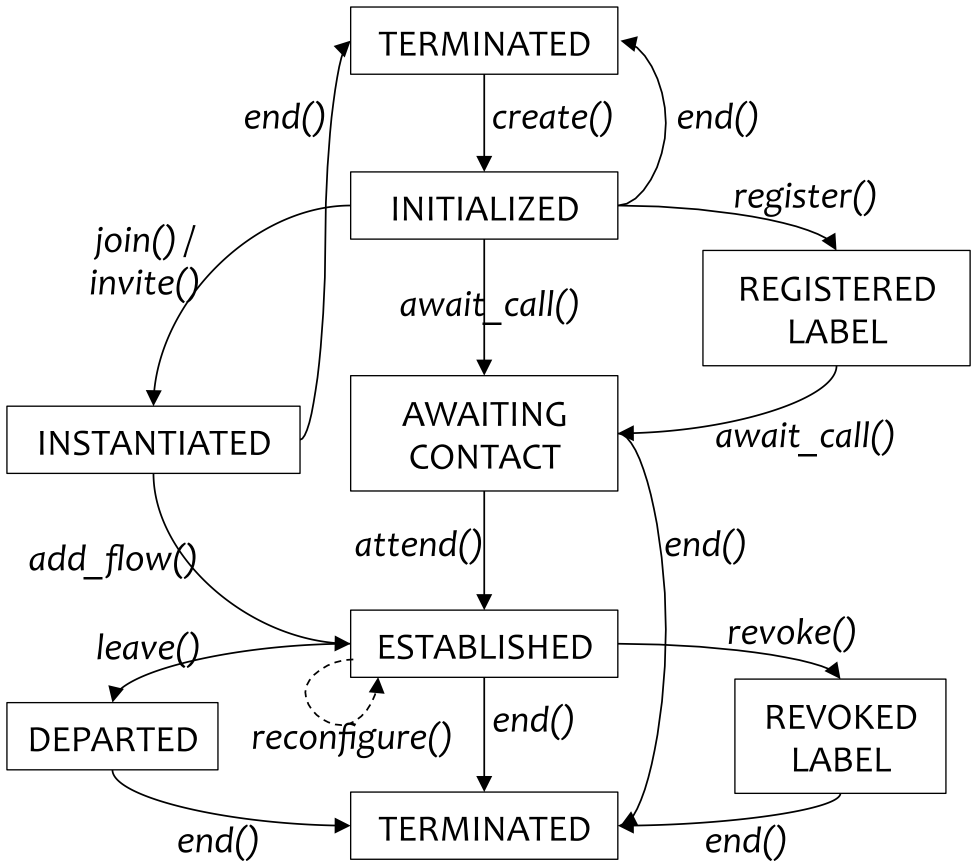
join(session)
invite(session, endpoint)
leave(session)

await_call(session)
attend(session)

reconfigure(session, verb)

register(label, endpoint)
translate(session, label)
revoke(session, label)

migrate(?)
suspend(?)



Flow-Related Primitives

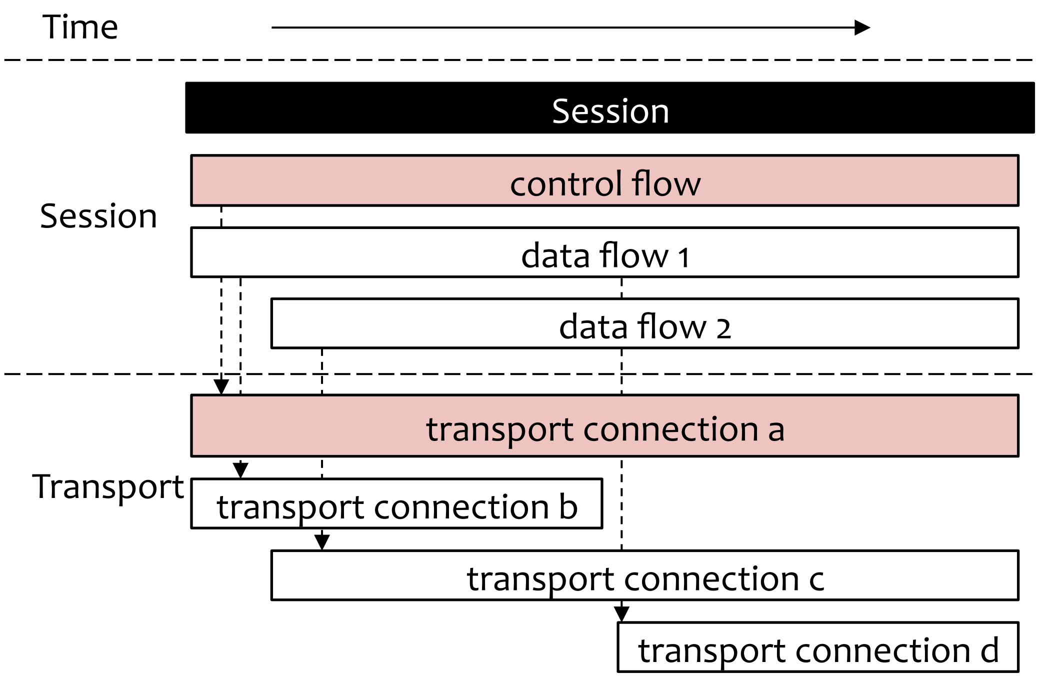
add_flow(session,
[structure,]
[type])
terminate_flow(session)

reconfigure(flow, verb)

read(flow)
write(flow)

Control Channel

- Enable exchange of control messages: verbs
  - Example: **refresh, suspend_flow, resume_flow**



Control Verbs

Session Management | Negotiation of Configuration | Data Transfer

```
{
    "VERB" : "refresh",
    "SOURCE" : "alice.node",
    "TRANSACTION ID" : "1872",
    "SESSION LABEL" : "a.session",
    "AUTH TOKEN" : "h@kl#S",
    "TIMEOUT" : 20
    "PAYLOAD": { "list":
        [{
        "END POINT LABEL" : "alice.node",
        "IP" : "192.0.1.222",
        "PORT": 5432
        }]}
}
```

What do Sessions contribute?

- Allows us to describe communications
- Allows management of conversation
  - Manage one or more flows and endpoints
- Enables negotiation of configuration
  - Example: Encrypted flows

- Avoids duplication of effort
  - Application of primitives on one or group of flows
    - Example: Apple, phone call over WiFi and cellular net.
  - Migration of session
    - Example: Chrome's Screencast

Summary & Plans

A Communications Model and Framework for Session-based Adaptive Networking

Model: Session-based Communication

1. Abstractions involving two or more participants [CONEXT'15]
   - Design: primitives and interactions
2. Separation of Session and Transport Semantics
   - Implications for communication patterns
3. Case Study: Context Awareness and Advantages [GLOBECOM'15]
   - Cascaded TCP [SC'12]

Realization: Enabling Extensions

1. Incremental Evolution [PFLDNeT'10]
   - How to extend and overcome limitations?
2. Reduce Duplication of Effort
3. Mobility & Virtual Machine Migration [ICCCN'13]
4. Resilient Transport [ICCCN'11]

Use: Dynamic Configuration Enabling New Paradigms

1. Control Protocol
2. Session-oriented communication paradigm
   - Middleboxes as first-class citizens (e.g., Engage firewalls, Inetd, tcp-wrapper)
3. Session based communication semantics
   - Privacy semantics per session (e.g., SSL)

Appendix

Related Work

	SCTP (2000)	TESLA (2003)	SST (2007)	SERVAL (2012)	MPTCP (2013)	Our ambition
Like TCP on the wire	✗	✓	✗	✗	✓	✓
Backwards compatible w/ apps	✓	✗ / ✓	✗ / ✓	✗	✓	✓
Backwards compatible w/ TCP stacks	✗	✗	✗	✗	✓	✓
Transport independent	✗	✗	✓	✗	✗	✓
Fault tolerant	✗	✓	✓	✓	✓	✓
Multihoming	✓	✗	✗	✓	✓	✓
Flow migration	✓	✗	✗	✗ / ✓	✓	✓
End point migration	✗	✗	✗	✗	✗	✓
Session abstraction	✗	✓	✗	✗	✗	✓

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Fault tolerant	✗	✓	✓	✓	✓	✓
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Flow migration	✓	✗	✗	✗ / ✓	✓	✓
End point migration	✗	✗	✗	✗	✗	✓
Session abstraction	✗	✓	✗	✗	✗	✓

Perhaps ahead of its time

Related Work

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End point migration	✗	✗	✗	✗	✗	✓
Session abstraction	✗	✓	✗	✗	✗	✓

Great idea; wasn't adopted – lack of backwards compatibility

Related Work

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End point migration	✗	✗	✗	✗	✗	✓
Session abstraction	✗	✓	✗	✗	✗	✓

Perhaps mobile computing begins to flourish

Related Work

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End point migration	✗	✗	✗	✗	✗	✓
Session abstraction	✗	✓	✗	✗	✗	✓

Multiple interfaces in mobile devices are put to use

Related Work

TCP is here to stay,
perhaps sockets too

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Session abstraction	✗	✓	✗	✗	✗	✓

Related Work

Lessons:

1) Avoid point solutions
2) Backwards compatibility is important

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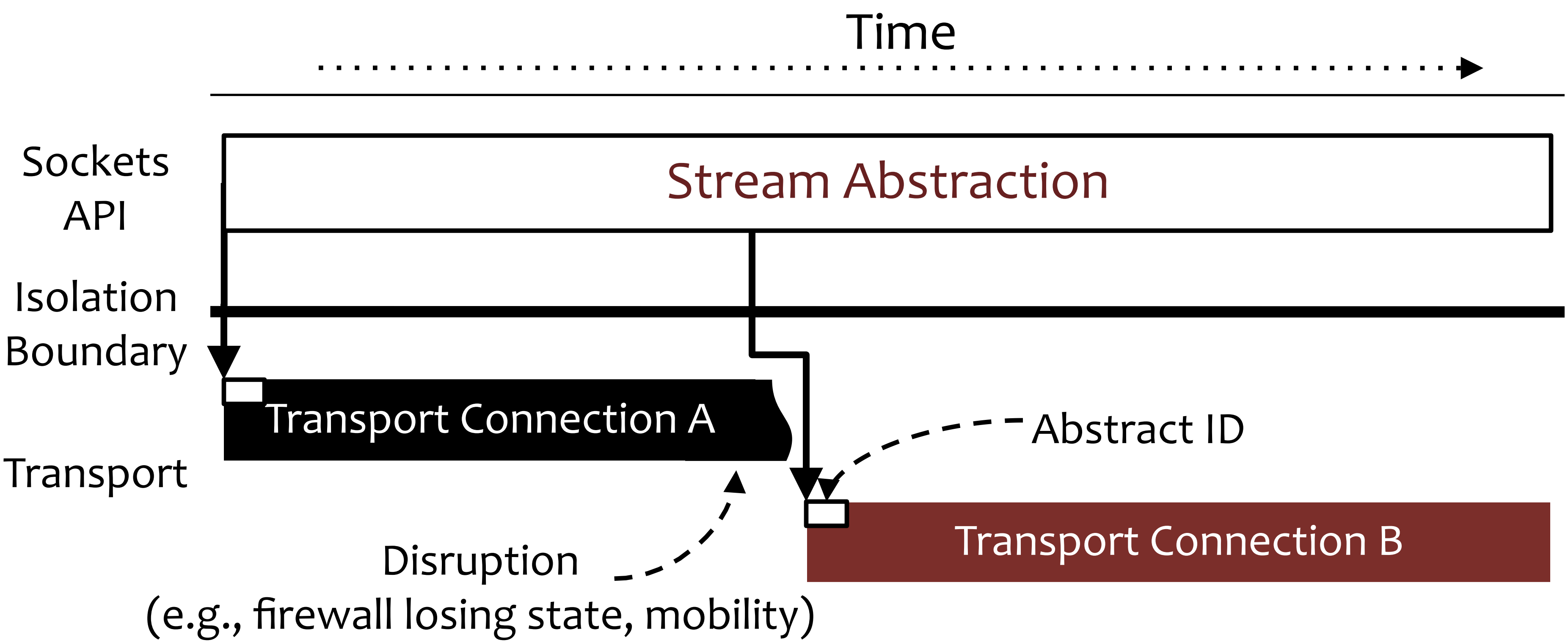
Session abstraction	✗	✓	✗	✗	✗	✓

Research Challenges

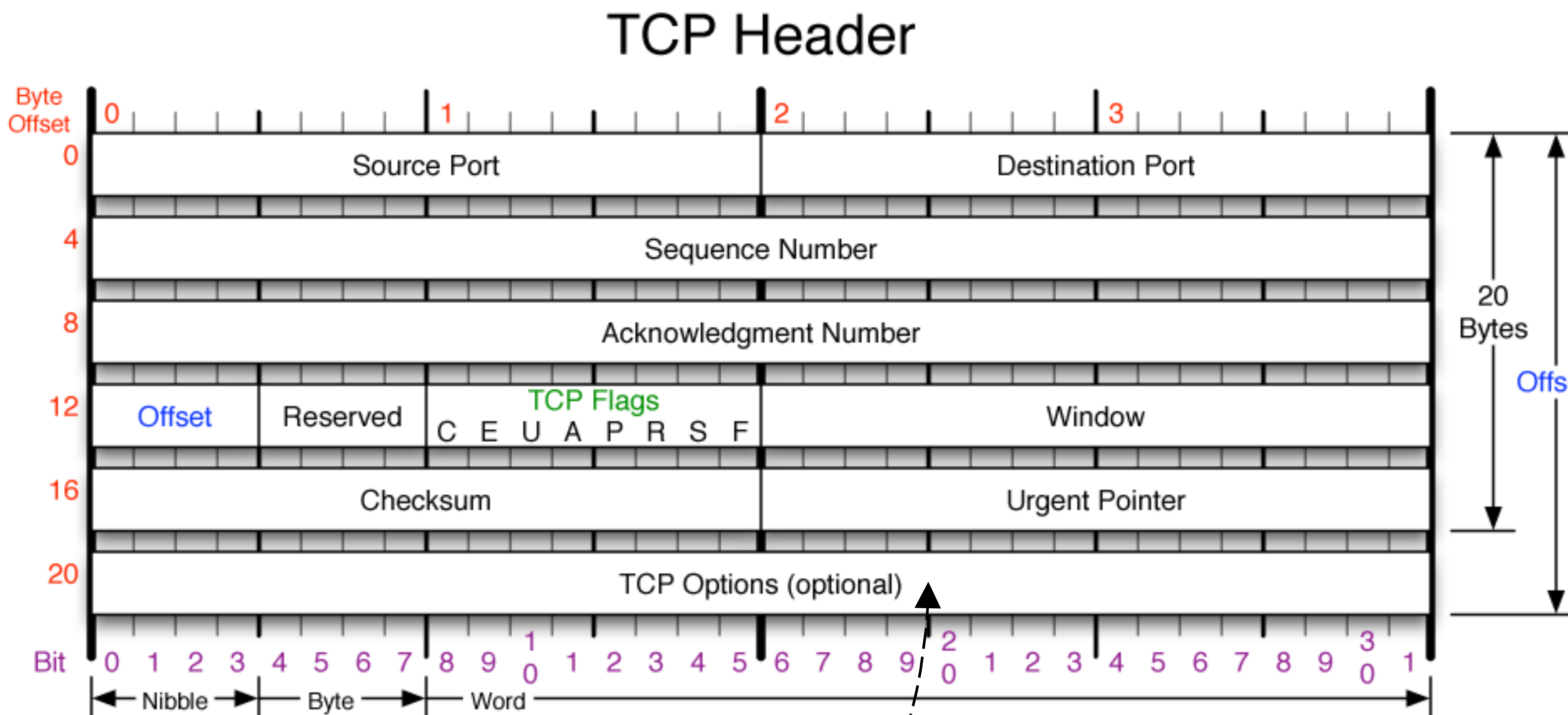
- Backwards-compatible extensions
  - How can we extend the existing network stack such that it allows *interaction with legacy stacks* and *applications*?
- Communication model
  - What abstractions do we need to enable *management of communication?*
  - How does *negotiation of configuration* enable context awareness?
  - How do these abstractions fit with existing designs?
- Framework
  - How do we develop a framework that enables *rich constructs*?
  - How do we *minimize duplication of effort*?

Logical Stream over TCP

- Application Stream flows between peers
  - Abstract ID: Independent of underlying transport



Backwards Compatible Extensions

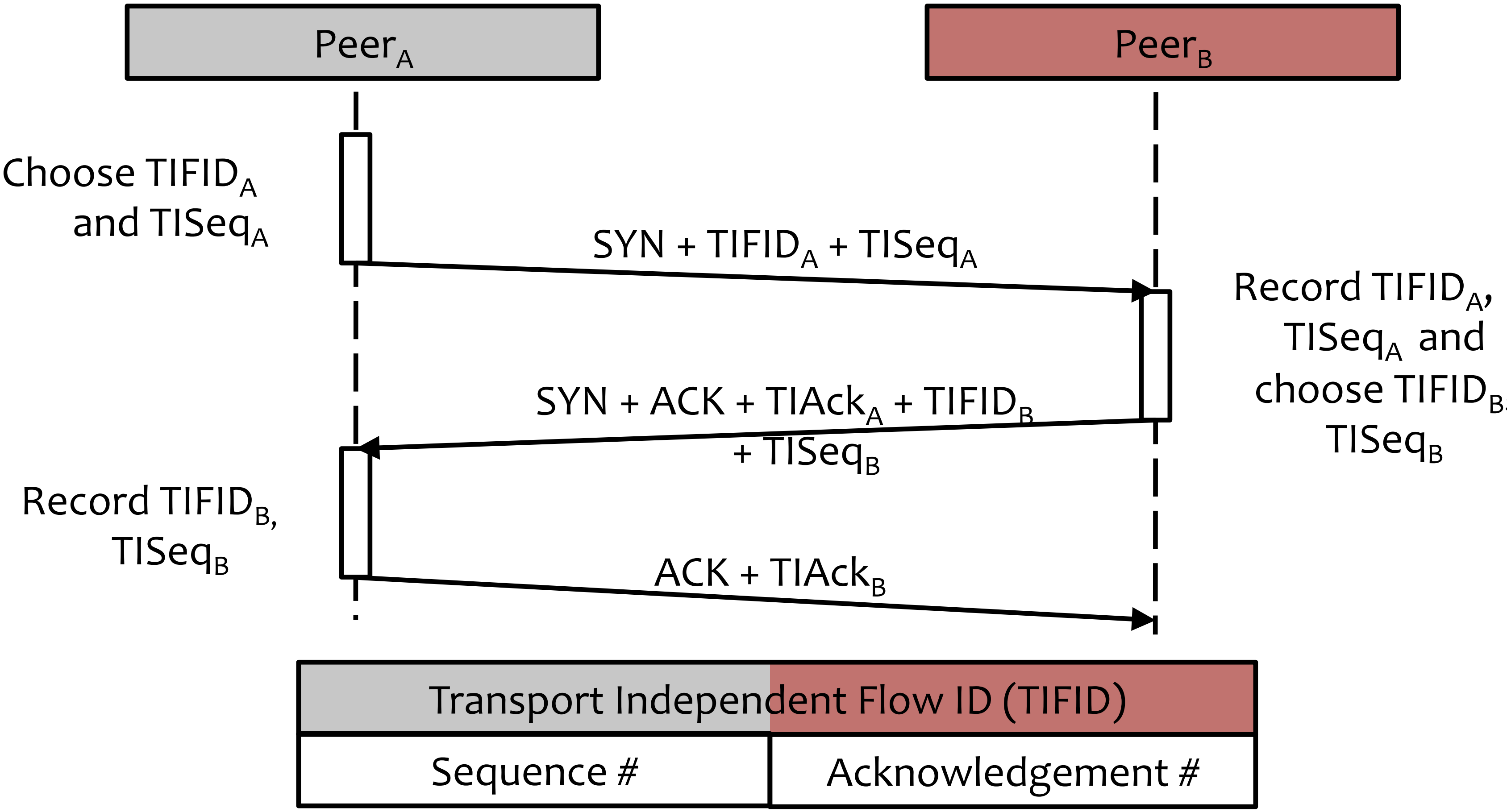


TCP Options space
(40 bytes)

20 bytes usable
(MSS 4, Window Scaling 3,
SACK 2, Timestamp 10)

TISeq – Transport Independent Sequence #
TIAck – Transport Independent Acknowledgement #

Backwards Compatible Extensions



TISeq – Transport Independent Sequence #
TIAck – Transport Independent Acknowledgement #

Definitions

- Communication
  - “a process by which **information** is **exchanged** between individuals through a **common system of symbols**, signs, or behavior.” (Merriam Webster Dictionary)

- Context
  - “The situation in which something happens; the **group of conditions** that exist where and **when something happens.**” (Merriam Webster Dictionary)

  - A **collection of attributes** that describe the **communication** and the **setting.** (our definition)

Why was state-of-the-art not adopted?

No killer application or disruptive technologies yet

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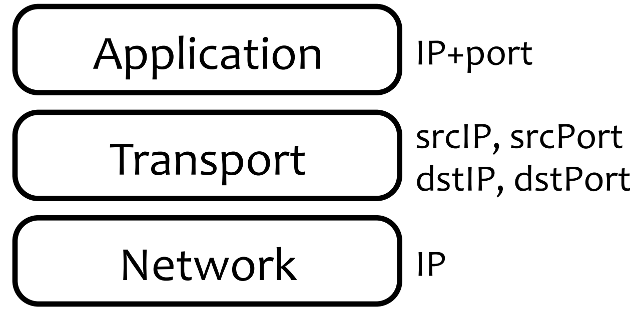
No killer application or disruptive technologies yet

What about:

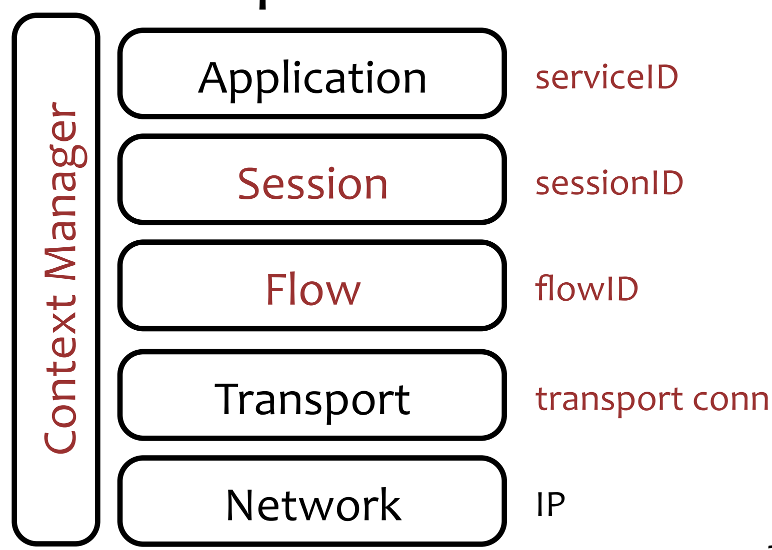
Abstractions

- **Data** plane abstractions
  - Clean separation of concerns
  - Richer set
    - Context
    - Event
    - Service
    - Session
    - Flow
    - Transport
    - Packet
    - Frame
    - (Network) Interface
    - Node
    - Facilitator
- Backwards compatibility

Overloaded Abstractions



Abstractions Redefined:
Clean separation of concerns

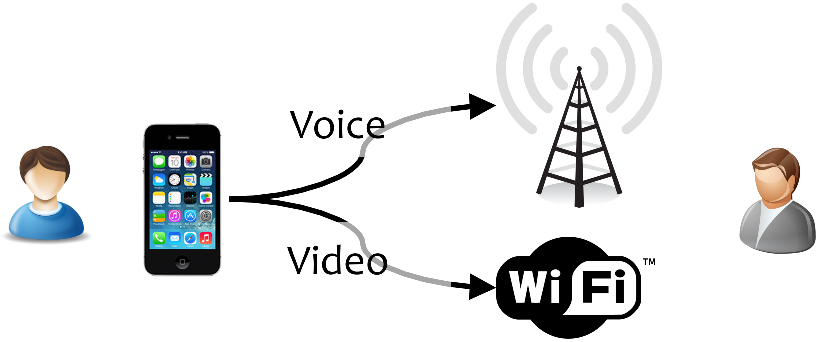


User Timeout Options Use Case

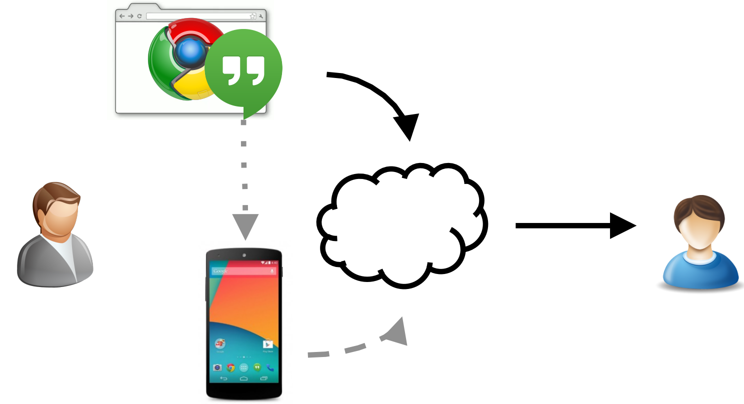
- Implementation
  - RFC 5482
    - TCP connection closed on timeout
      - No ACK before threshold
    - User Timeout Options
      - Define per connection timeout
      - Implemented using TCP socket options - SO_SNDTIMEO
    - Challenge for extension
      - Limited free space if typical TCP options are in use
        - Maximum Segment Size (4 octets)
        - Window Scaling (3 octets)
        - SACK (2 octets)
        - Timestamp (10 octets)
  - Publication discussing context manager
    - Abstractions, Architecture & API/interface and Implementation (UTO use case)

Long Term Goals

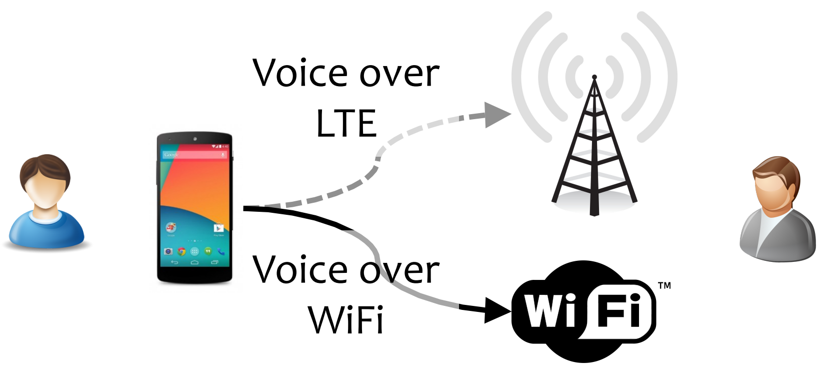
- A model that enables use of context in which communication happens
  - Abstractions & notion of communication context
    - Sessions, multipath comm., hybrid transport etc.
  - Architecture
    - Protocol design, functions, roles and interfaces
  - Framework
    - Prototype implementation and use-case applications



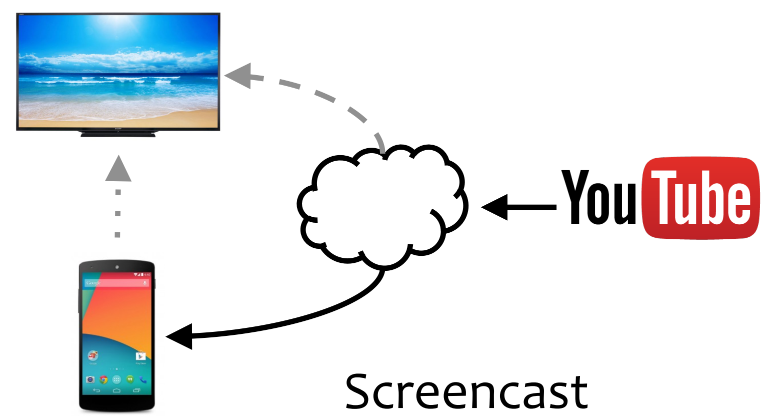
Voice & video over different networks with Apple Facetime



Call migration from browser to cell phone using Google Hangouts

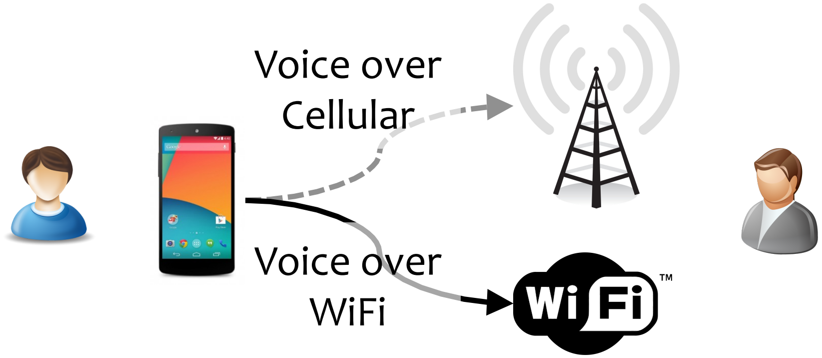


Seamless handoff w/ WiFi calls



Screencast

Icons downloaded from iconarchive.com



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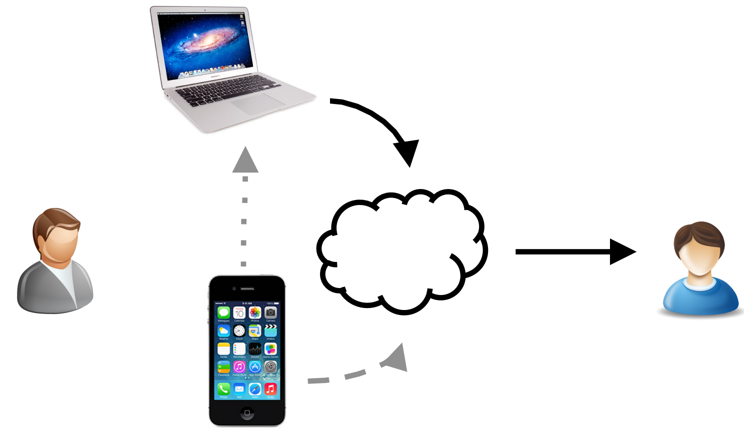

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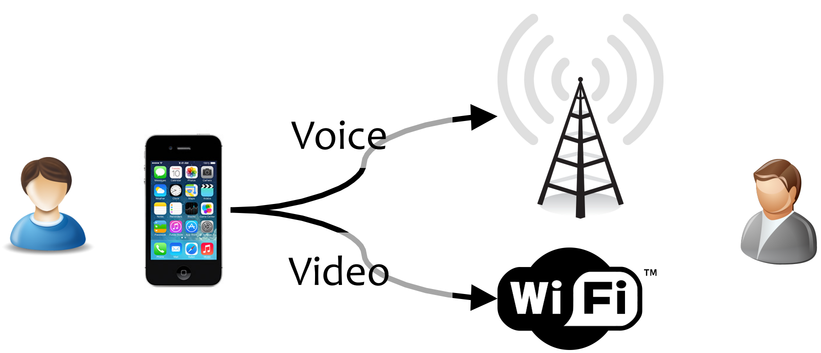
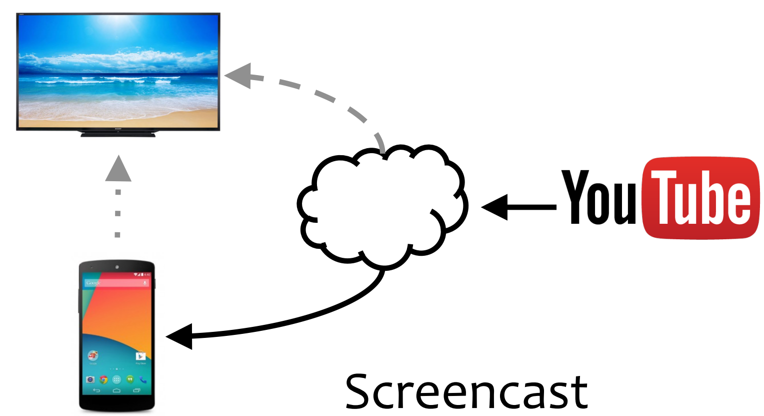


Voice & video over different networks
(Apple Facetime)



Screencast
(Google Chromecast)

Research Challenges

- Backwards-compatible extensions
  - How do we extend the network stack such that it allows *interaction with legacy stacks* and *applications*?

Research Challenges

Backwards compatibility?

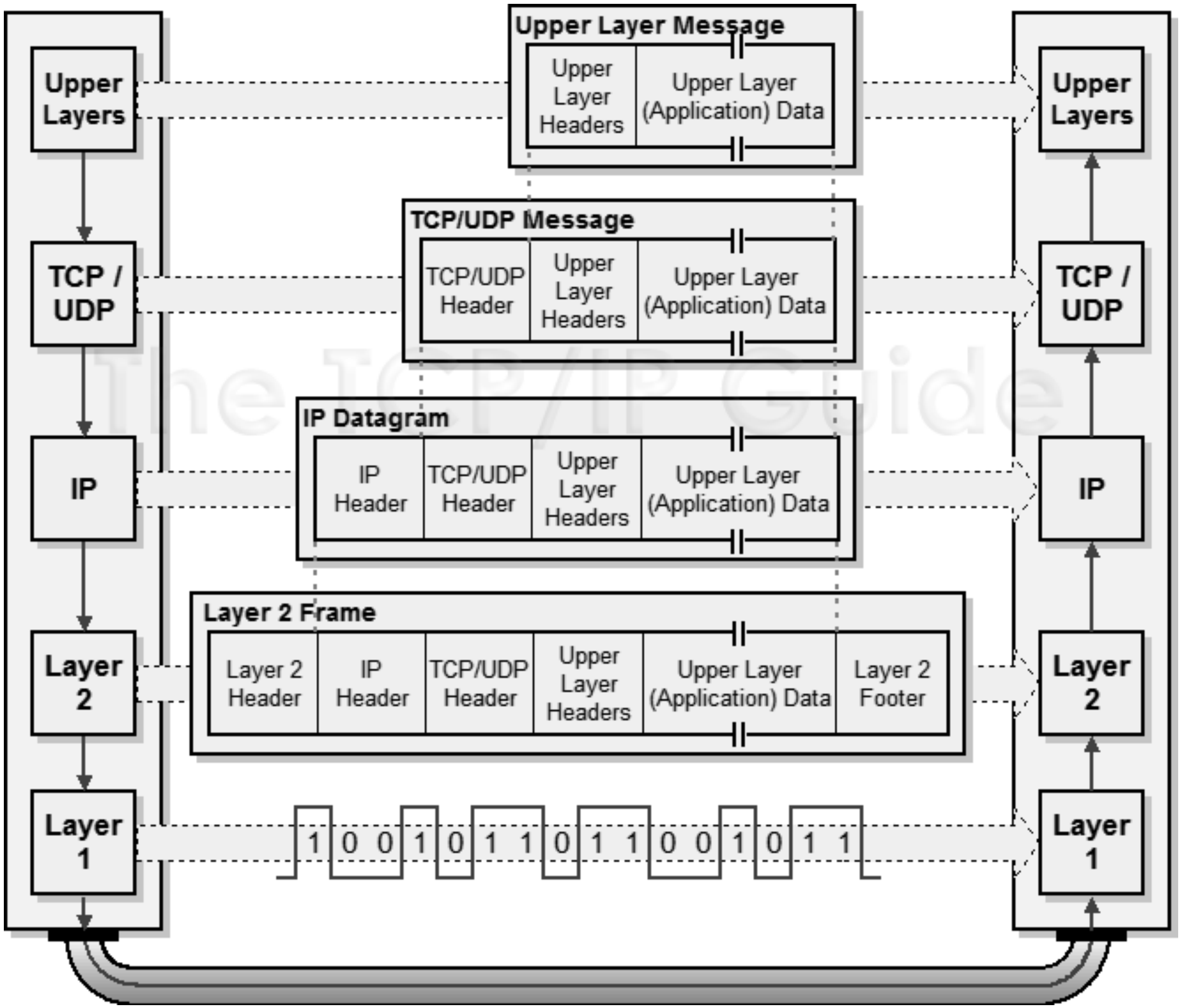
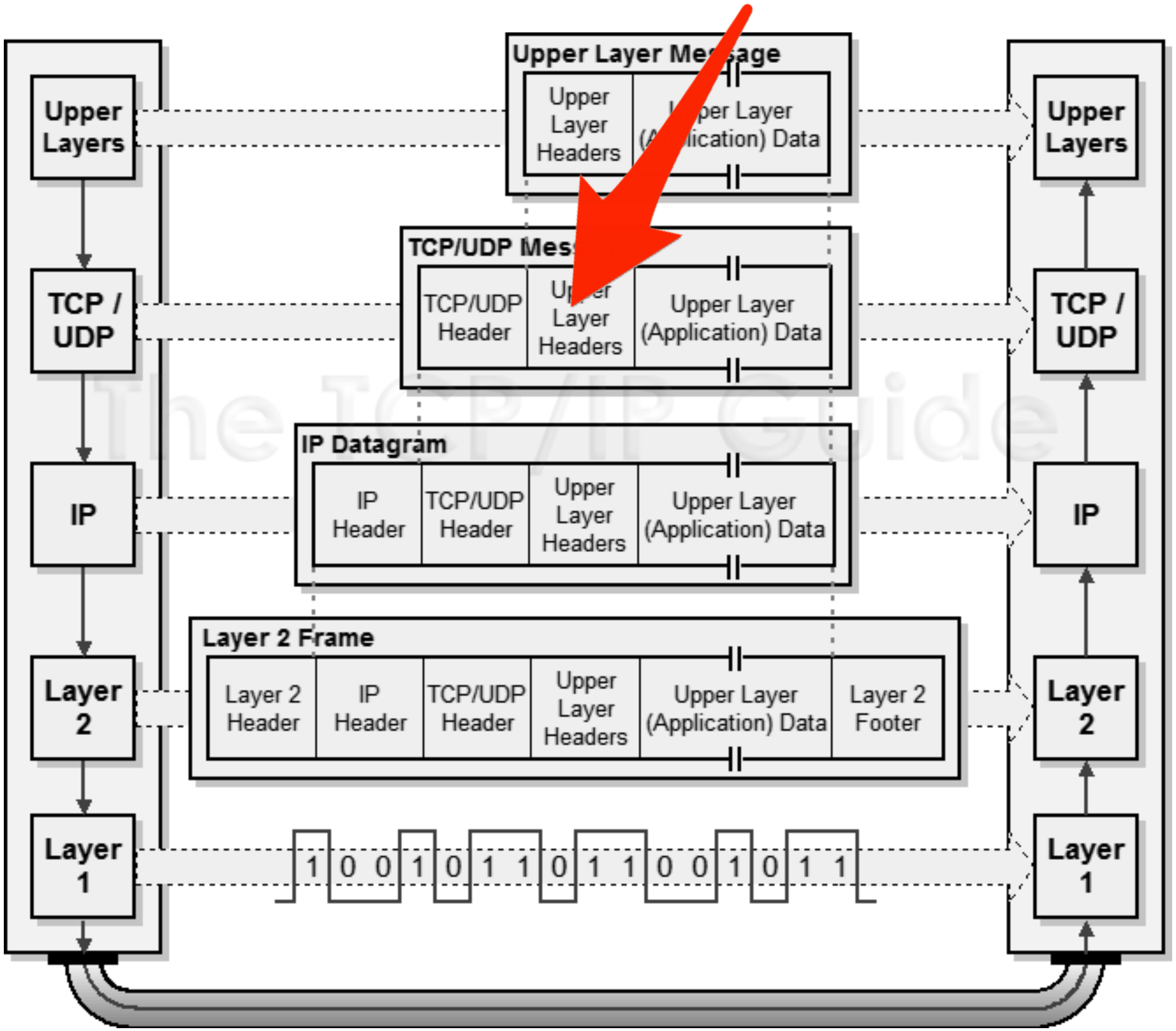


Image source: tcpipguide.com

Research Challenges

Backwards compatibility?

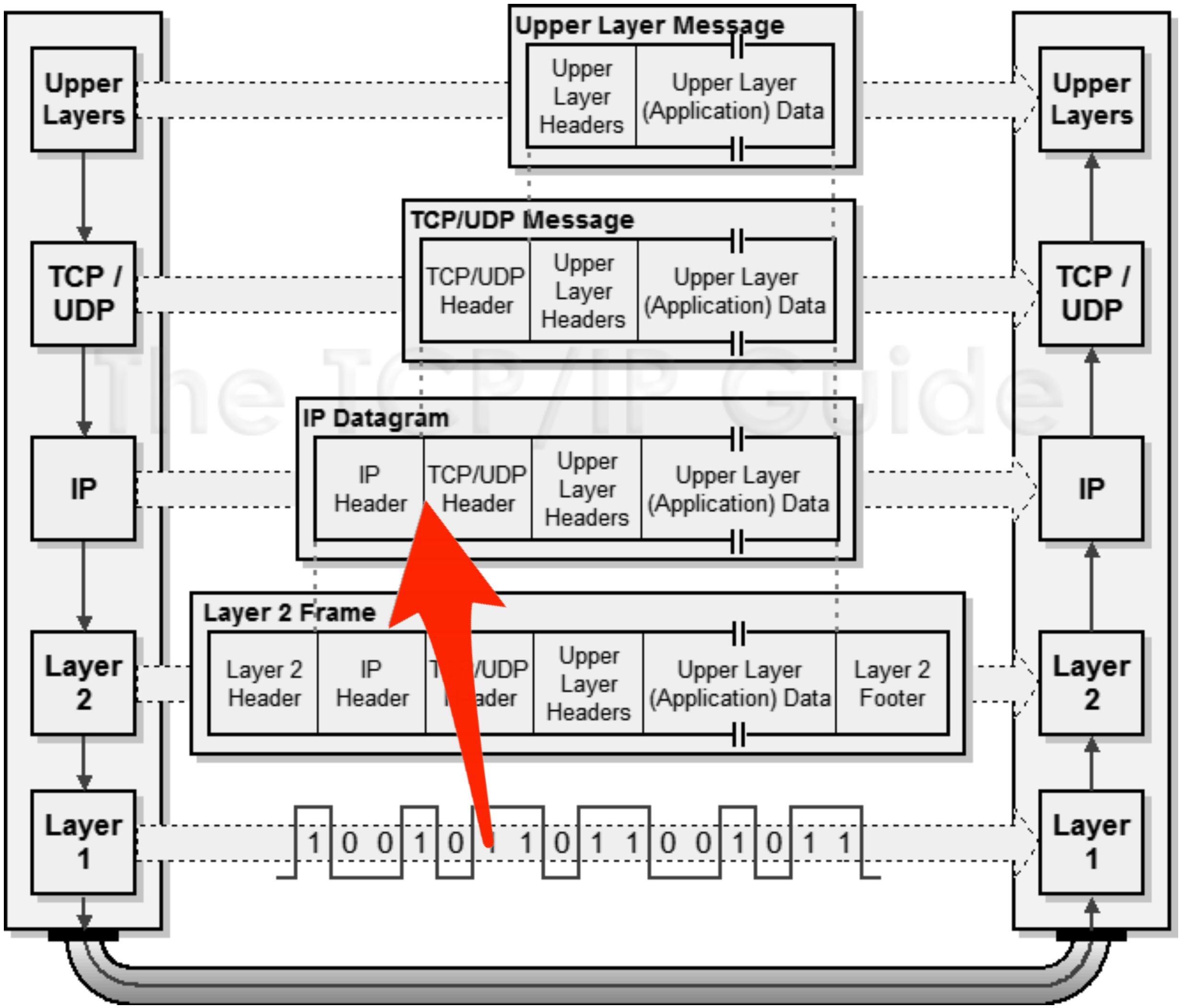


- Add layer above TCP?
  - *Legacy Stack will cause the app to fail!*

Image source: tcpipguide.com

Research Challenges

Backwards compatibility?

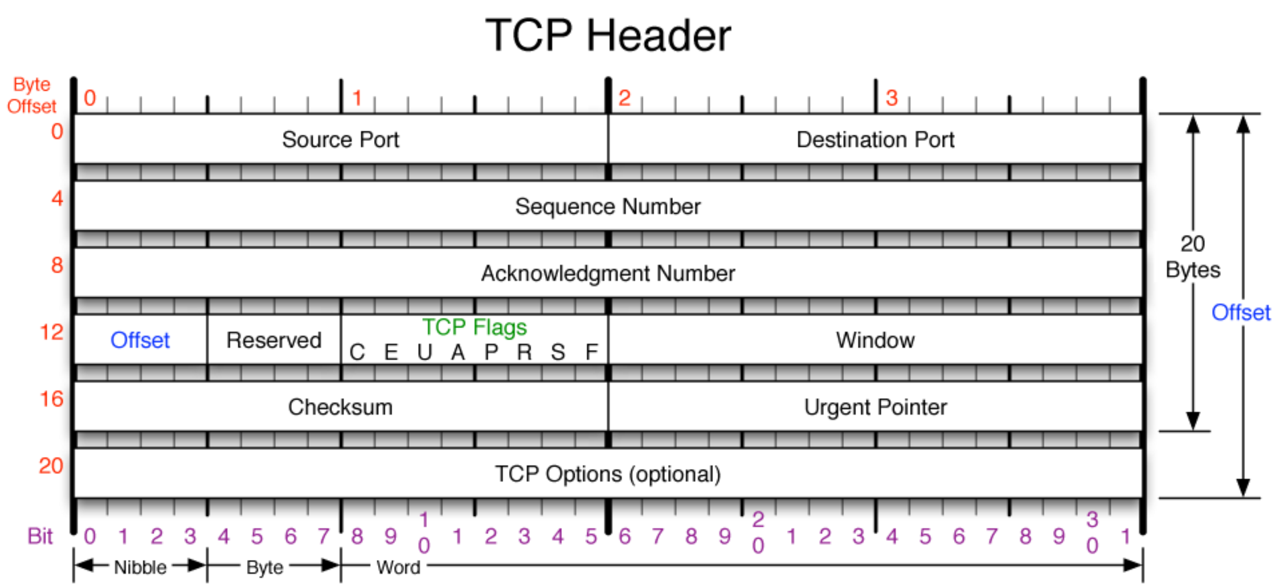


- Add layer above TCP?
  - *Legacy Stack will cause the app to fail!*
- Add layer below TCP?
  - *Middleboxes will not let the packets through!*

Image source: tcpipguide.com

Research Challenges

Backwards compatibility?



- Add layer above TCP?
  - *Legacy Stack will cause the app to fail!*
- Add layer below TCP?
  - *Middleboxes will not let the packets through!*
- Modify TCP?
  - *Legacy Stacks!*
  - *Middleboxes!*

Virginia Tech Invent the Future

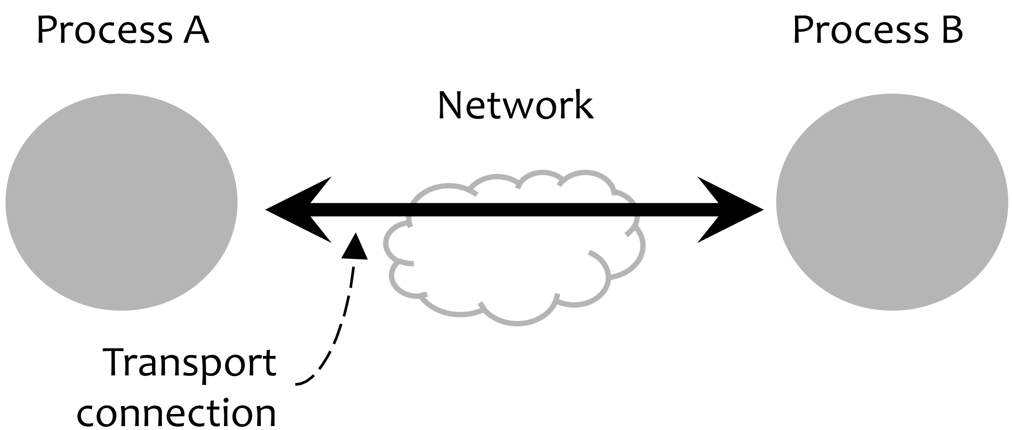
Image source: software-engineer-training.com

SyNeRG synergy.cs.vt.edu

Research Challenges

- Backwards-compatible extensions
  - How can we extend the existing network stack such that it allows *interaction with legacy stacks* and *applications*?
- Communication model
  - What abstractions do we need to enable *management of communication?*
  - How does *negotiation of configuration* enable context awareness?
  - How do these abstractions fit with existing designs?

Research Challenges Communication Model?

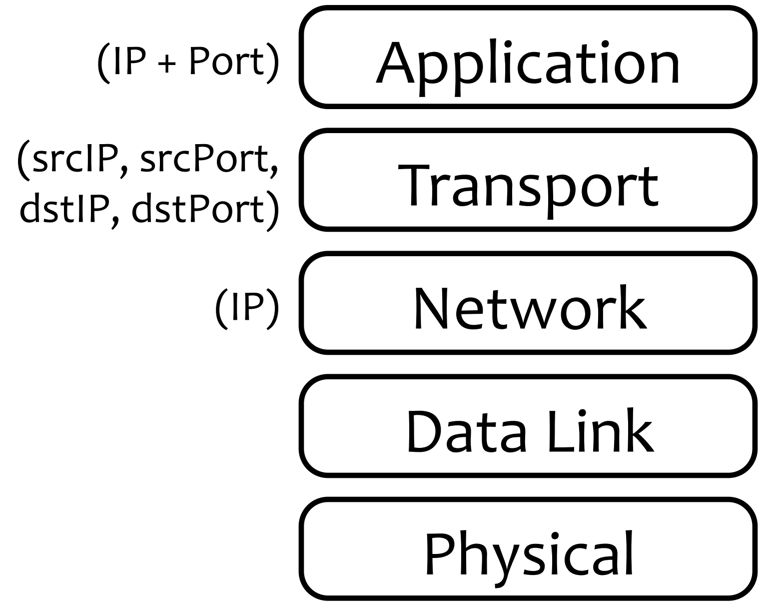


- Transport connection
  - Stream
  - Datagram

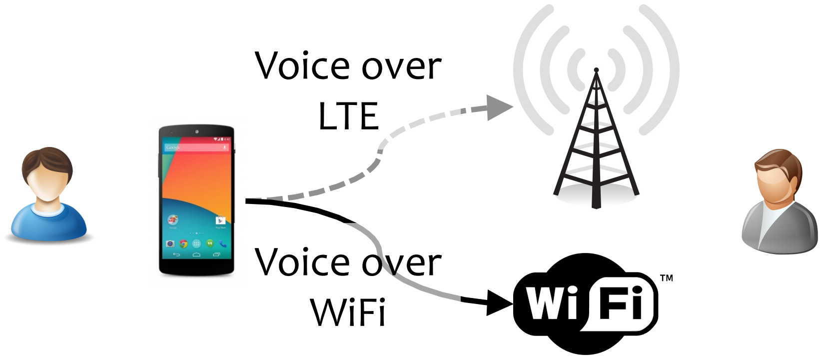
Research Challenges

Communication Model?

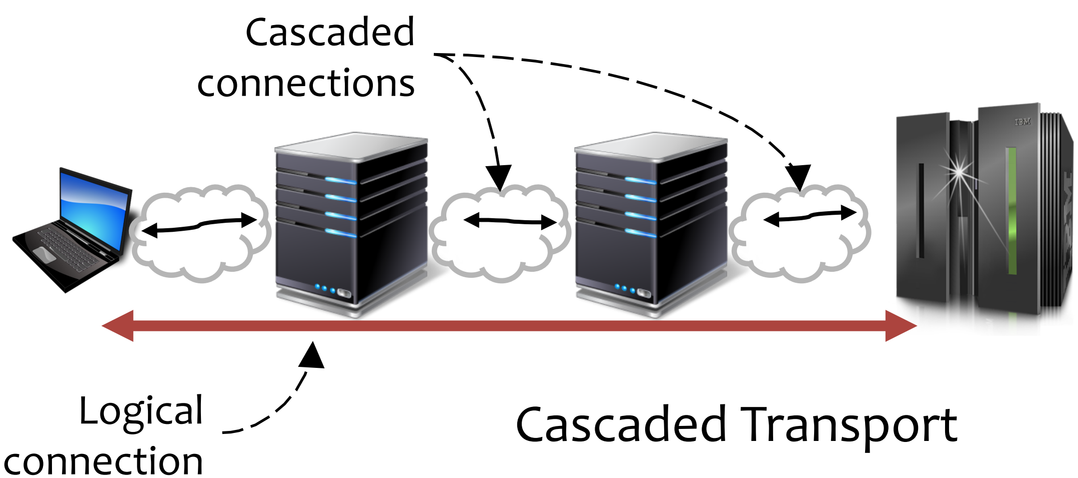
- Overloaded Abstractions
  - Coupled with roles spanning multiple layers
- No notion of:
  - Independent IDs for services
  - Session/conversation
  - Flow (/logical stream)



Research Challenges Implementation Framework?



Seamless handoff w/ WiFi calls



Cascaded Transport

- How to implement negotiation of configuration?
- What support to provide and what not to?

Research Contribution

- Backwards-compatible extensions
  - Enabling TCP extensions [PFLDNeT'10]
  - Resilient communication [ICCCN'11]
  - Virtual machine migration across networks [ICCCN'13]
- Communication model
  - Session abstraction [work in progress]
- Implementation framework
  - Case study about cascaded transport [SC'12 (Poster), GLOBECOM'13]

Other contributions

- User-space impl. of fault-tolerant transport
  - Seamless disconnection/reconnection over TCP [BBL'10]

- User-space impl. of video server migration across networks
  - Transport-agnostic extensions, using UDP [BBL'11]