Tuning Multipath TCP for Interactive Applications on Smartphones

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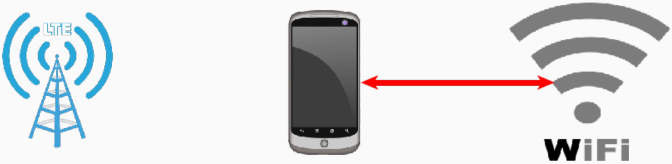
Smartphones are Multi-Homed Devices

What is wrong today with TCP?



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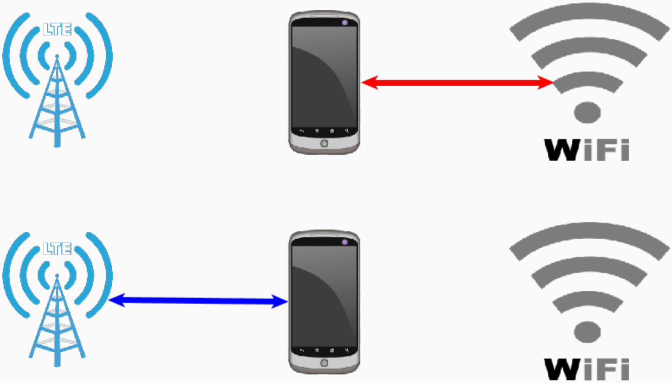

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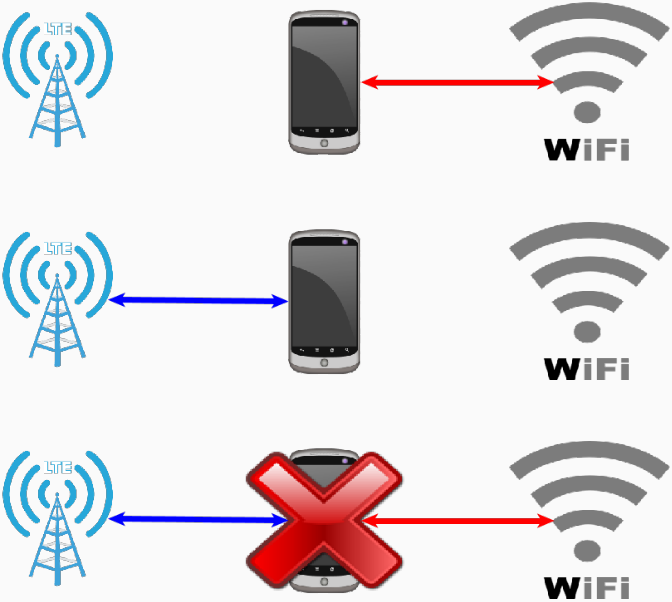

Multipath TCP on Smartphones

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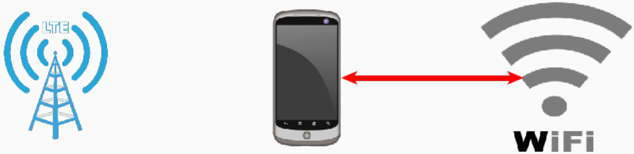

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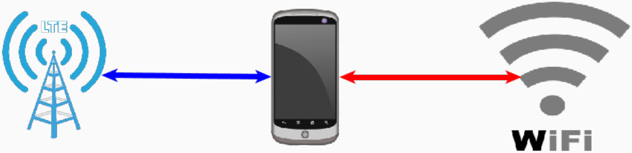

Multipath TCP on Smartphones

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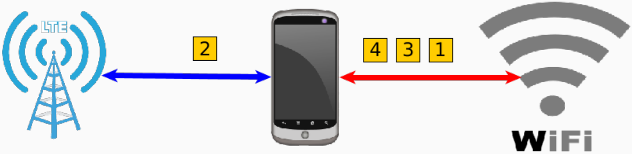

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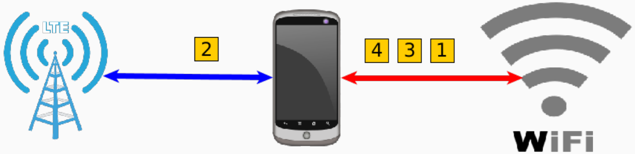

Siri, iOS11

SOCKS Proxy

Imperfections with Multipath TCP on Smartphones

MultiMob

Evaluation with Real Users

Conclusion

Imperfections with Multipath TCP on Smartphones

Smartphone Traffic $\neq$ Bulk Transfers

Linux implementation of Multipath TCP

- Mainly bandwidth aggregation driven
- But most of the connections are (very) short in bytes
  - Most are **latency-sensitive**
  - Growing importance of interactive applications
    - Apple Siri, Google Now, Amazon Alexa,...
  - Multipath = **network resiliency under mobility**

Multipath TCP Cellular Subflow Usage

"Cost less than"

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$
WiFi
<
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LTE

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LTE

Smartphone = data consumers

- Servers take most of the scheduling decisions
    - Prefer **lowest perceived latency** path by default
- Ability to define cellular as **backup** path
    - Use non-backup paths unless they all failed

Multipath TCP Cellular Subflow Usage

WiFi & cellular path creations as soon as possible

- *make-before-break* for fast network handover
- But most cellular subflows do not see **any** data
  - WiFi is often sufficient
    - Short connections, low application push rate, no mobility...
  - **Network + energy waste**
    - Cellular can consume as much as a screen 100% on

MultiMob

Imperfections with Multipath TCP on Smartphones

MultiMob

- Giving Control to the Client
- Break-Before-Make
- Immediate Reinjections

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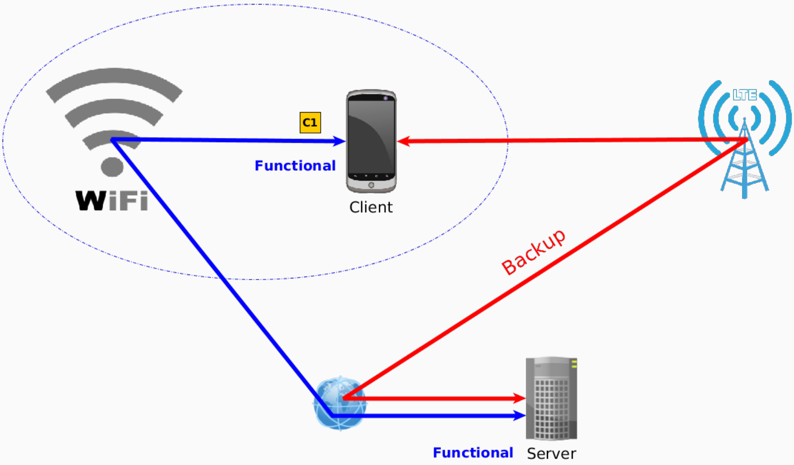
MultiMob

Giving Control to the Client

An Illustrative Example - Request/Response Traffic



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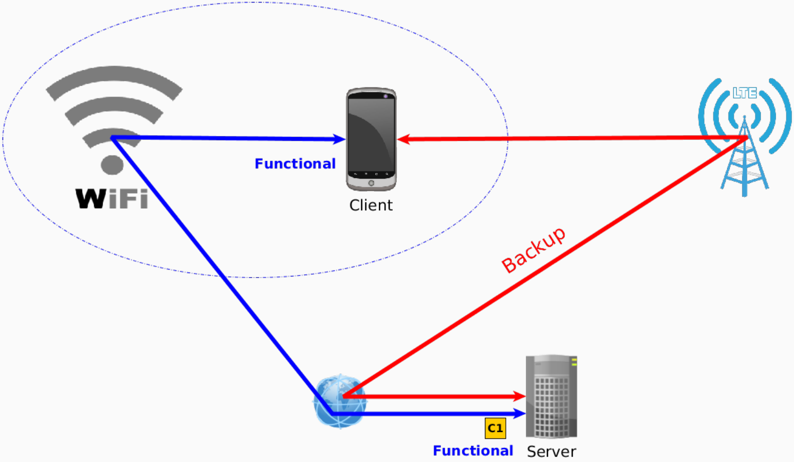

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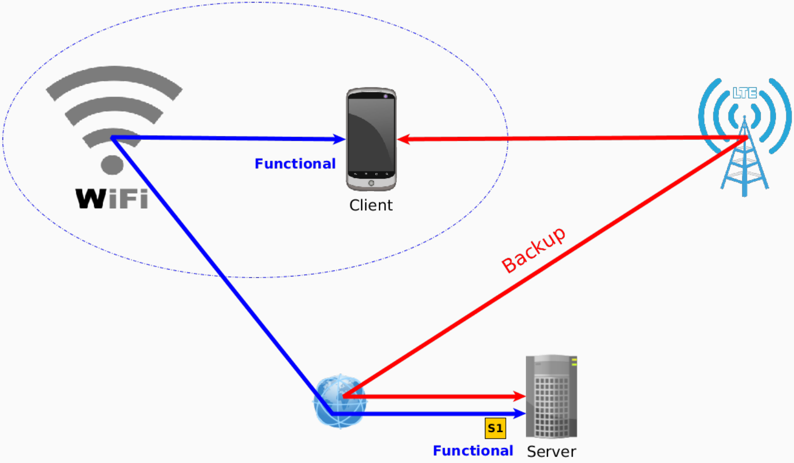

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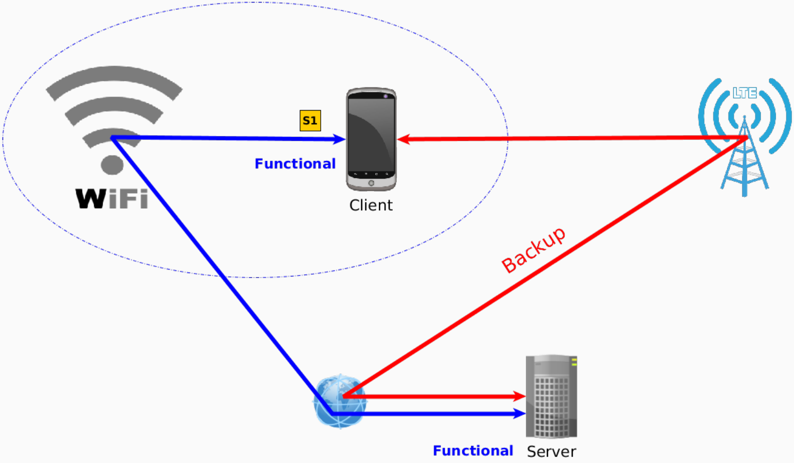

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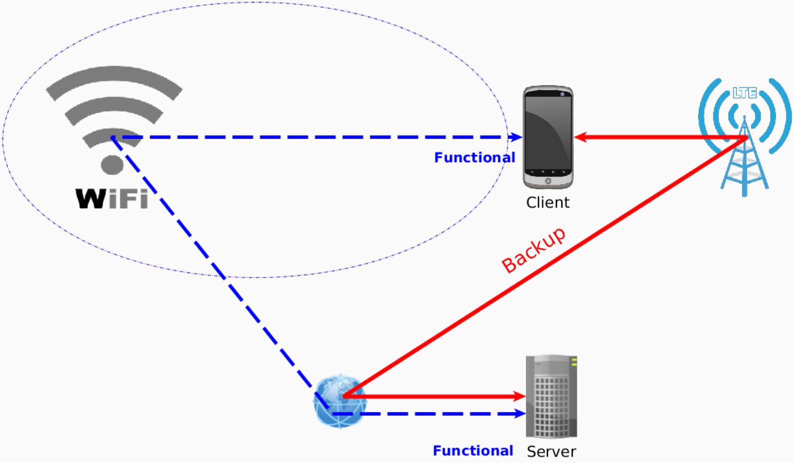

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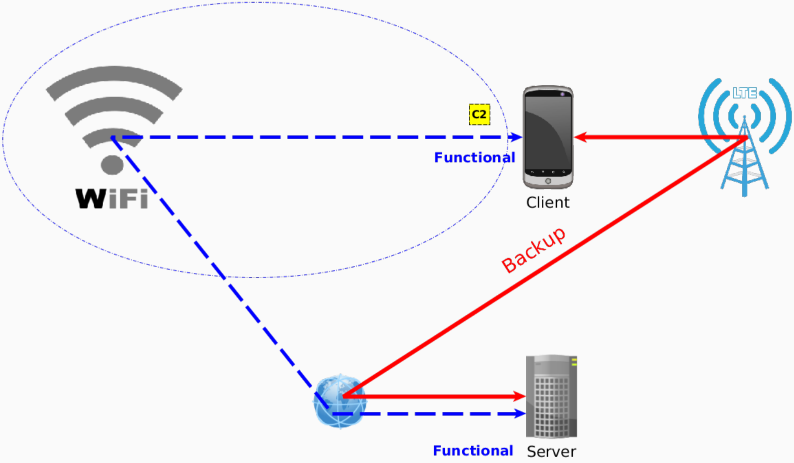

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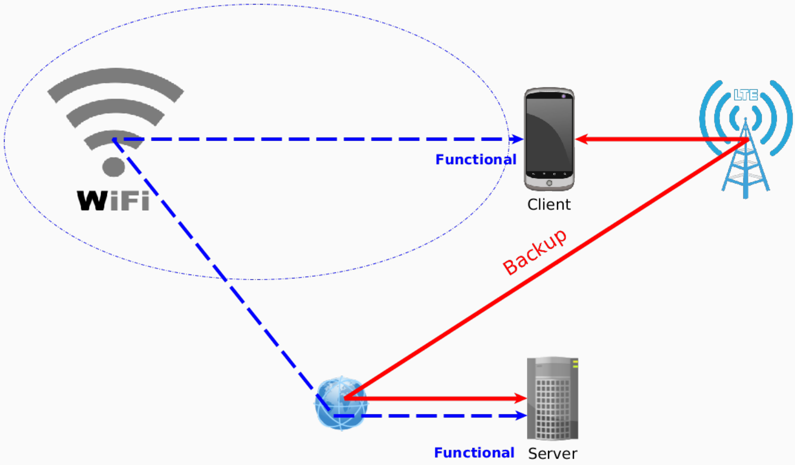

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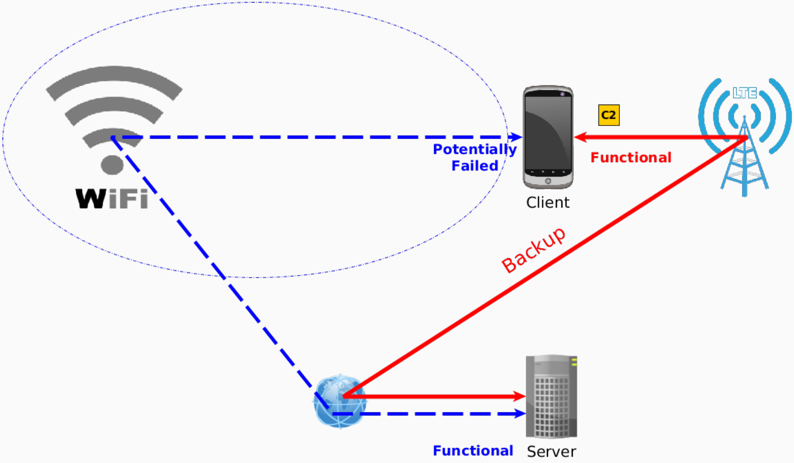

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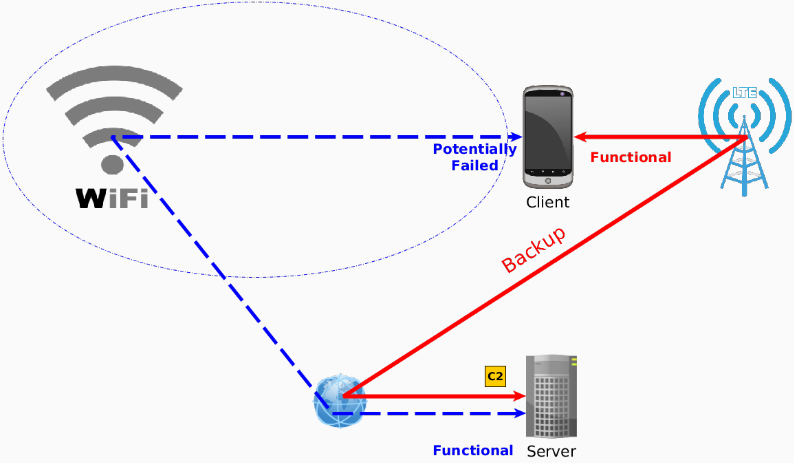

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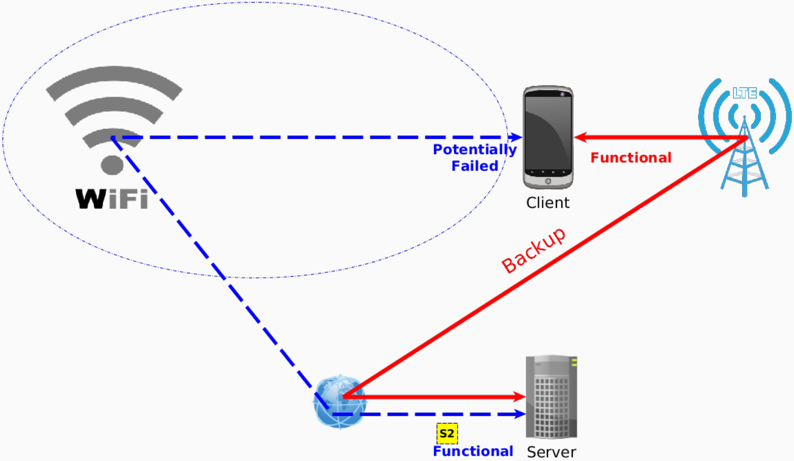

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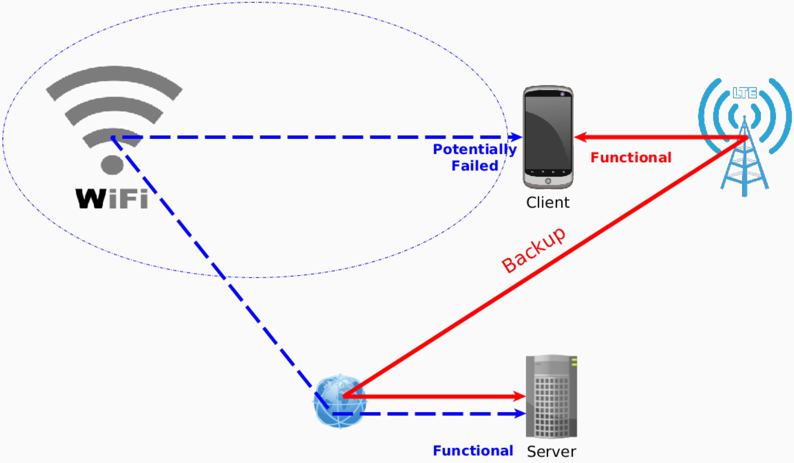

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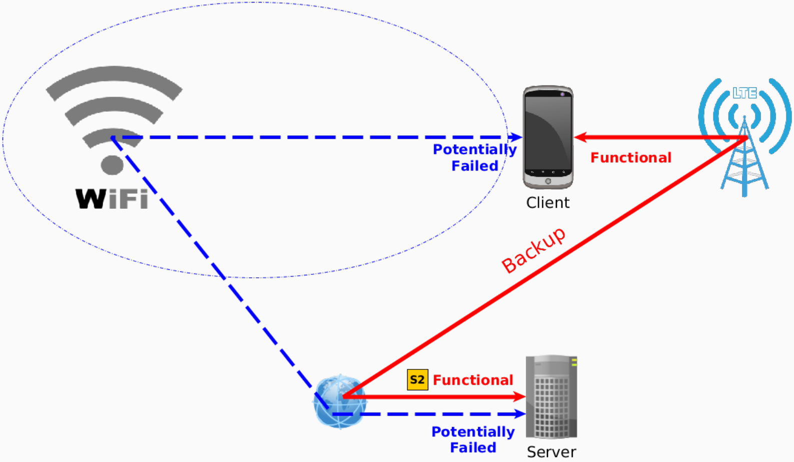

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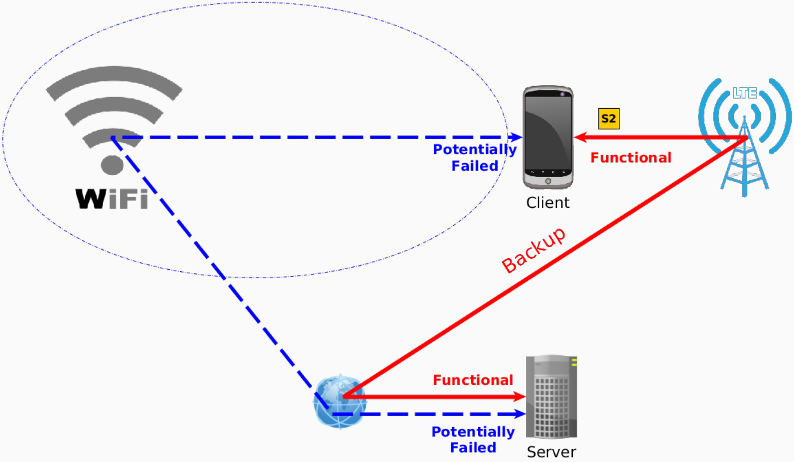

MultiMob Server Scheduler

→ Let the server follow the path used by client

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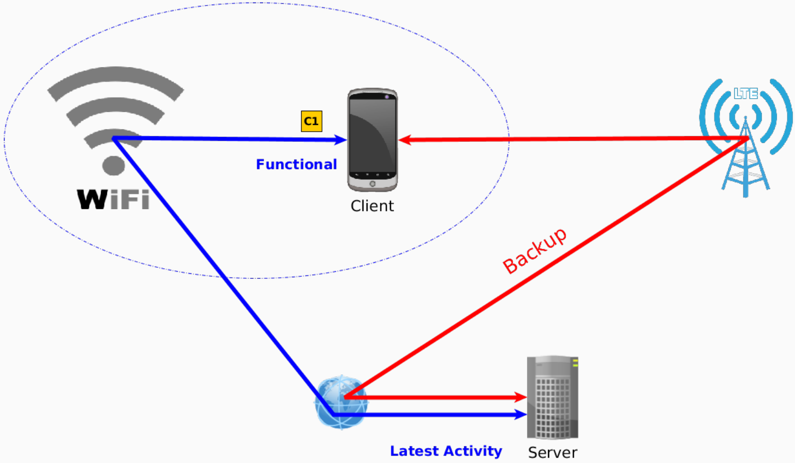

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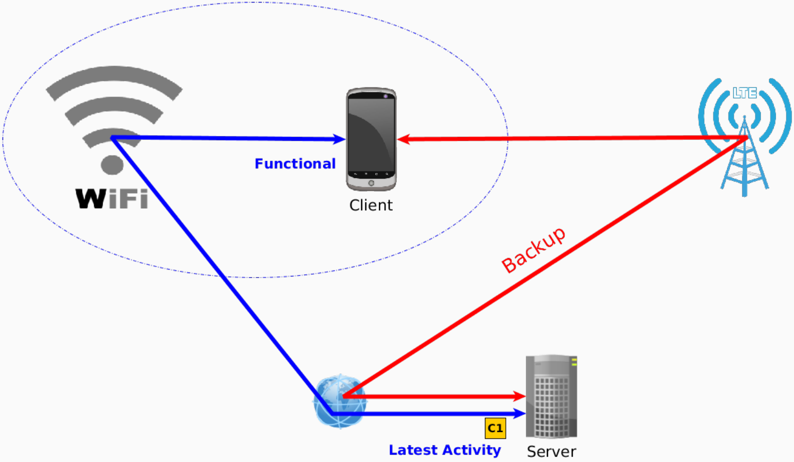

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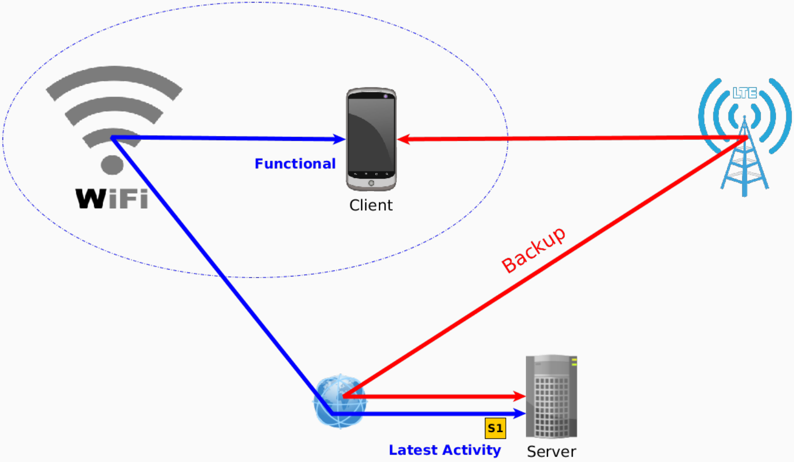

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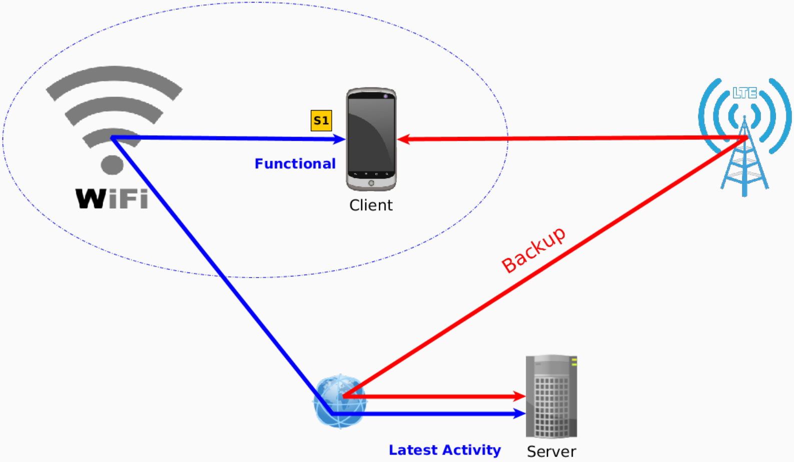

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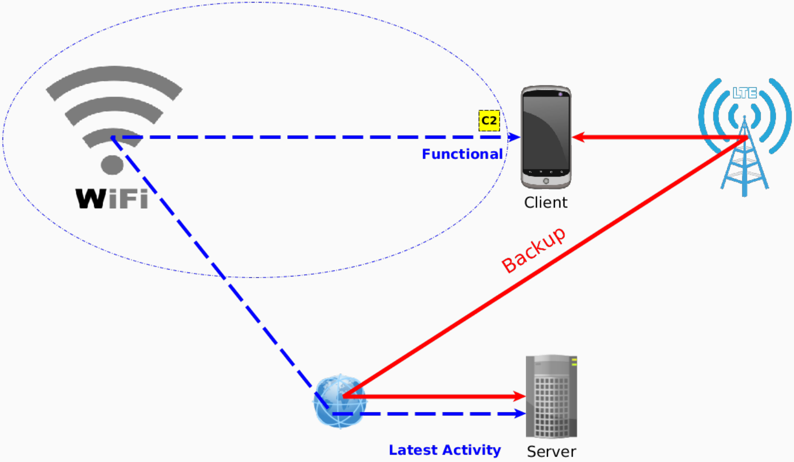

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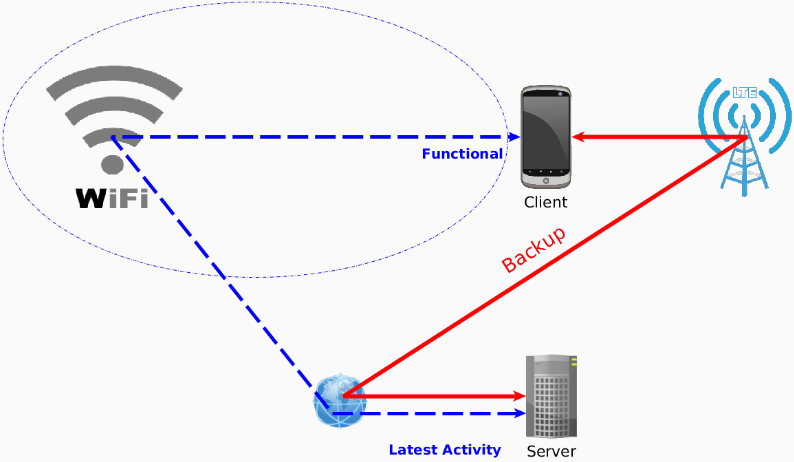

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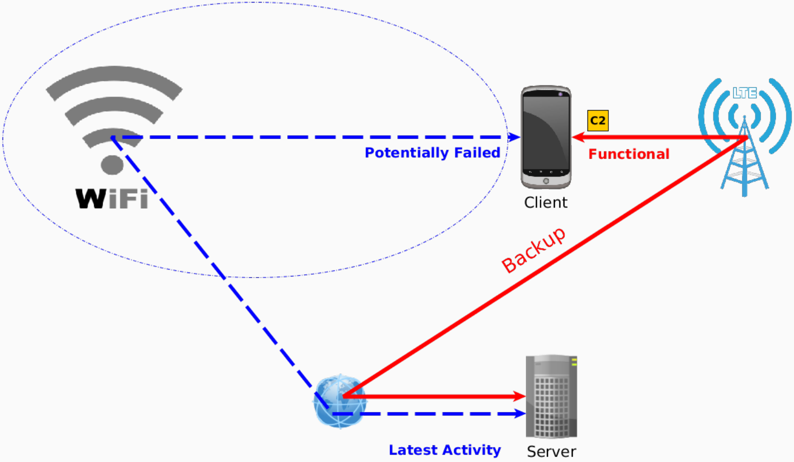

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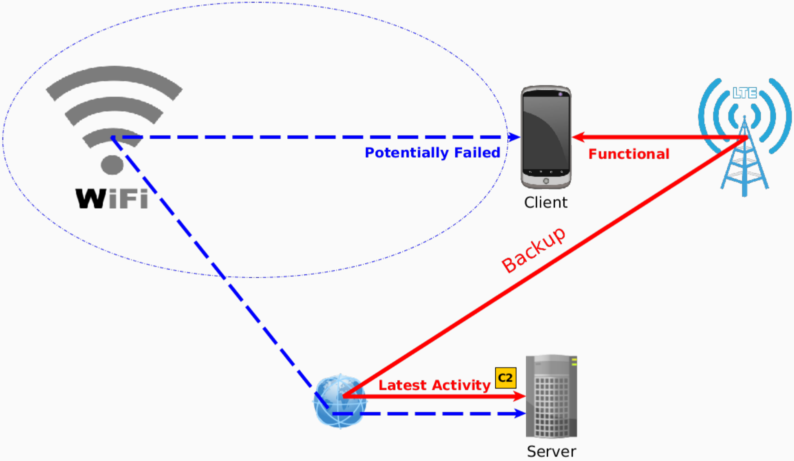

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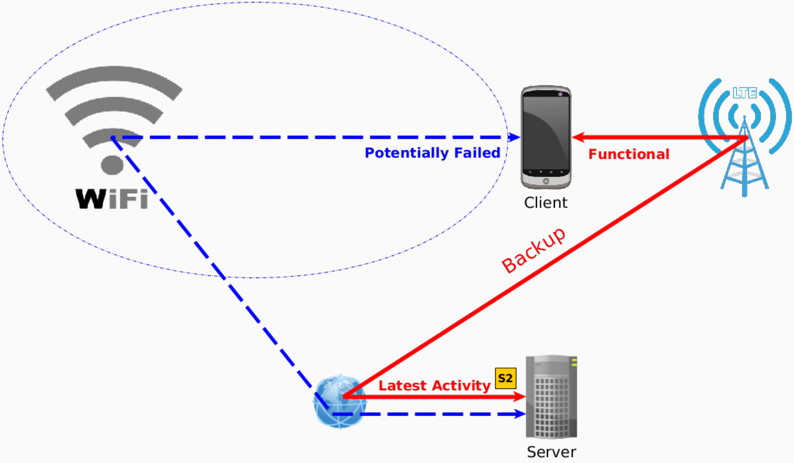

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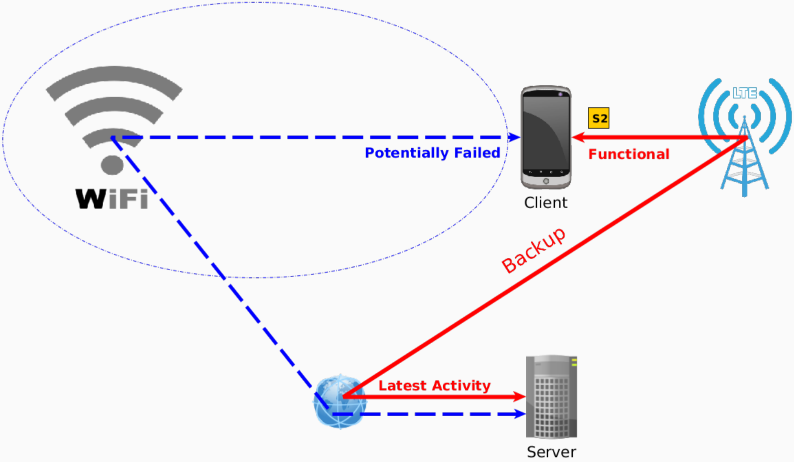
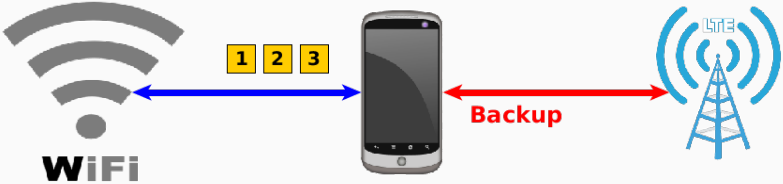


MultiMob

Break-Before-Make

Current Make-Before-Break Approach



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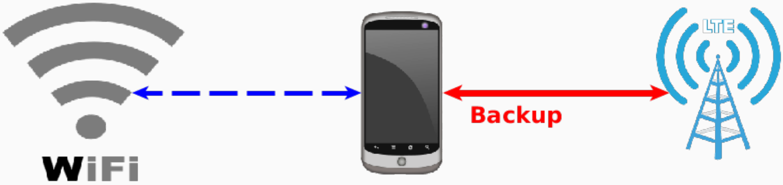

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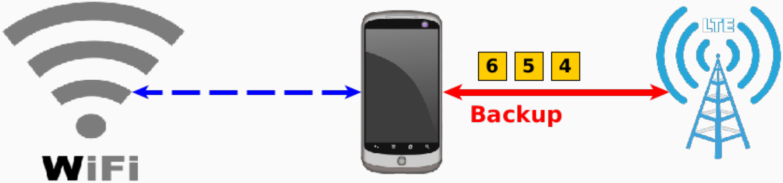

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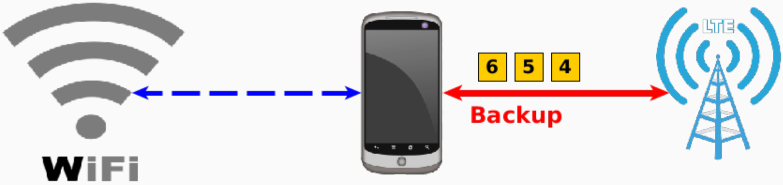
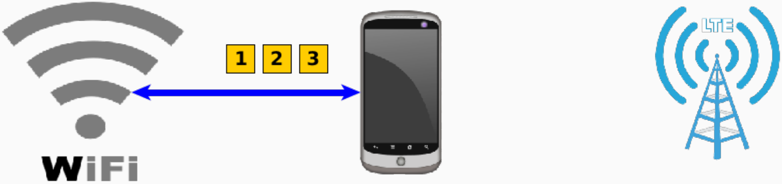


→ Minimizes amount of data sent over cellular

- Yet lot of energy wasted by LTE usage...

Proposed Break-Before-Make Approach



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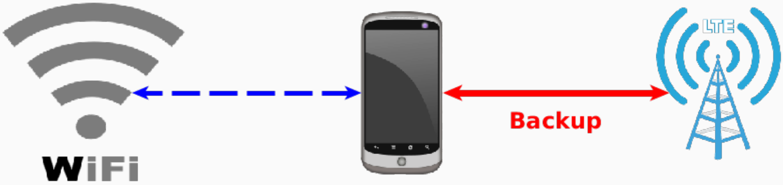

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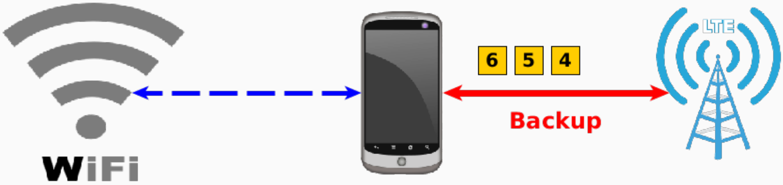

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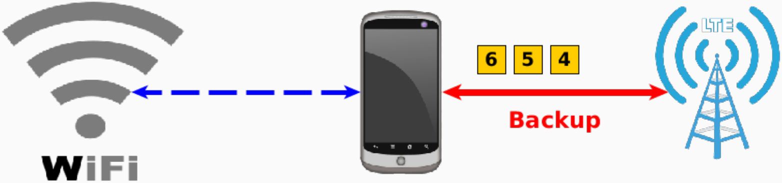
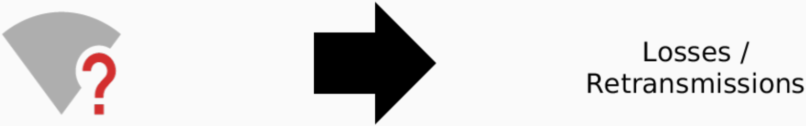


→ No LTE usage if cellular path not needed!

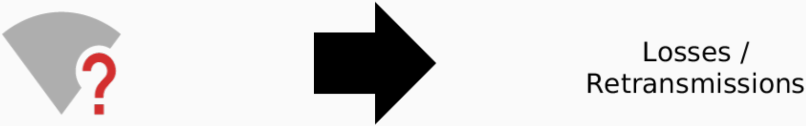
- But need to quickly detect bad wireless networks

Quick Failure Detection



Losses /
Retransmissions

Quick Failure Detection



Losses /
Retransmissions

Proposing an **in-kernel Multipath TCP oracle**

- Periodically compute statistics about *netpaths*
  - Netpath = (IP_{src},IP_{dst}, Net interf.)
- Trigger backup creation upon excessive losses/retransmissions
  - + prevents primary use when bad

IP_{src}	IP_{dst}	Net interf.	TCP sfs	TCP stats
1.2.3.4	4.5.6.7	WiFi	[tp_1, tp_3]	sloss 2%, ...
2.3.4.5	5.6.7.8	Cellular	[tp_2]	sloss 0%, ...
2.3.4.5	4.5.6.7	Cellular	[tp_4, tp_5]	sloss 15%, ...

Table 1: Oracle monitoring table example.

MultiMob

Immediate Reinjections

Limiting Handover Delay

The backup cellular path creation is delayed

- Nice from a energy consumption point of view...
- ...but incurs larger app perceived latency in mobility cases

Furthermore, additional Multipath TCP path creation takes time...

Improving Establishment of Additional Subflows

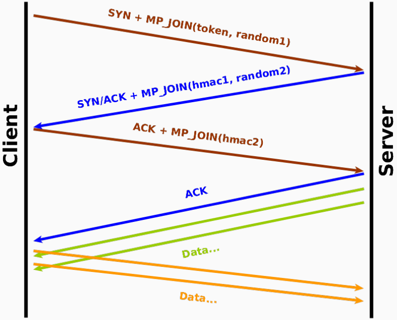
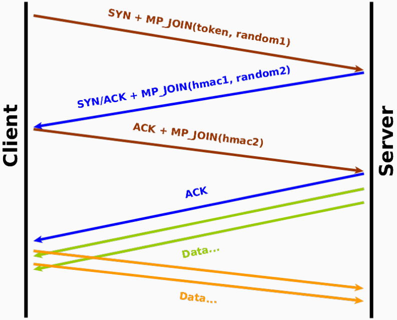

Client
Server
SYN + MP_JOIN(token, random1)
SYN/ACK + MP_JOIN(hmac1, random2)
ACK + MP_JOIN(hmac2)
ACK
Data...
Data...

Figure 1: Normal `JOIN`.

Improving Establishment of Additional Subflows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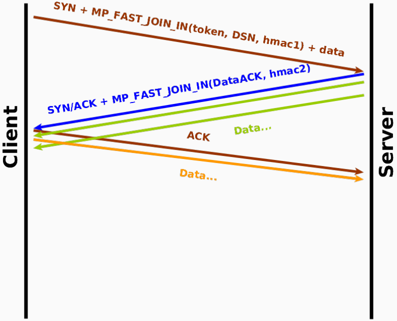
Client
Server
SYN + MP_FAST_JOIN_IN(token, DSN, hmac1) + data
SYN/ACK + MP_FAST_JOIN_IN(DataACK, hmac2)
Data...
ACK
Data...

Figure 2: Fast JOIN with data.

Evaluation with Real Users

Methodology

Half-dozen of smartphone users

- Running Android 6.0.1
- Two sets of users
  - Running vanilla Multipath TCP (with/without backup)
  - Running MultiMob

Performing interactive traffic measurements

- Light bursty request/response traffic, see paper for details
  - Observe delay between request sent and response received
- Running 80 s once motion is detected
- Only consider tests with both WiFi/LTE online at beginning

Interactive Traffic - Maximal Request Delay over Tests

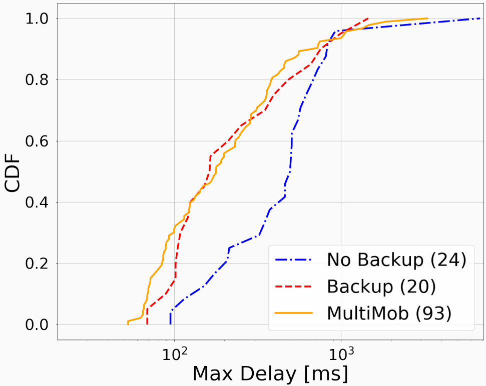

Figure 3: Maximal delays.

- MultiMob does not perform worse than Vanilla Multipath TCP
- Using multiple paths is not always beneficial

Interactive Traffic - Energy Consumption ("static" tests)

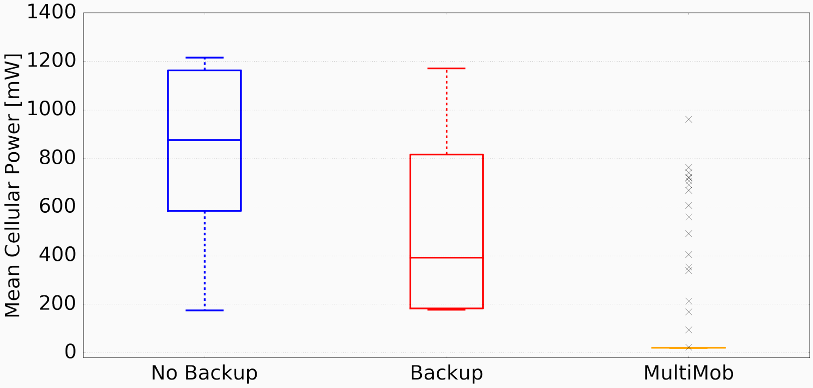

Figure 4: Estimated mean cellular power, WiFi not lost.

- **MultiMob consumes much less cellular energy!**

Conclusion

Conclusion

- Vanilla Multipath TCP not efficient from energy viewpoint
- MultiMob: Multipath TCP tuned for smartphones
    - Keep similar performances
    - Lower energy consumption
    - Lower LTE radio resource usage
- MultiMob is available

`http://multipath-tcp.org/multimob`

Thanks for your attention!

Feel free to ask questions!

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Coping with Corner Cases - "Single" Bulk Download

- Client detects bad networks with lost sent packets
- Client creates backup paths once bad network detected
- One connection experiences issues, others react

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→ What about single bulk download without background traffic?

- By default, server does not create paths
    - NAT, firewalls,...

Receive Timer

Exchange additional information at connection level

- Send RTO_{sender} to peer
- `MP_IDLE` bit in DSS to indicate no more data to send (now)

Allows to setup a **receive timer**

- Reset to RTO_{sender} if activity without `MP_IDLE`
- Stop if received data with `MP_IDLE`

If receive timer fires, create backup path

Assessing Receive Timer

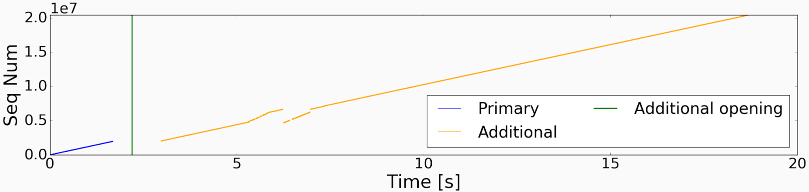

Figure 5: Time-sequence graph of server to client flow from client side perspective for a HTTP GET of 20 MB. Primary has 100% losses at 1.5 s.

- Client opens additional path after inactivity period
- Once established and data detected as lost, server continues the connection on the additional path