An Untold Story of Middleboxs in Cellular Networks

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Overview

1. Introduction to NetPiculet
2. NATs in Cellular Networks
3. Firewalls in Cellular Networks
4. Conclusion

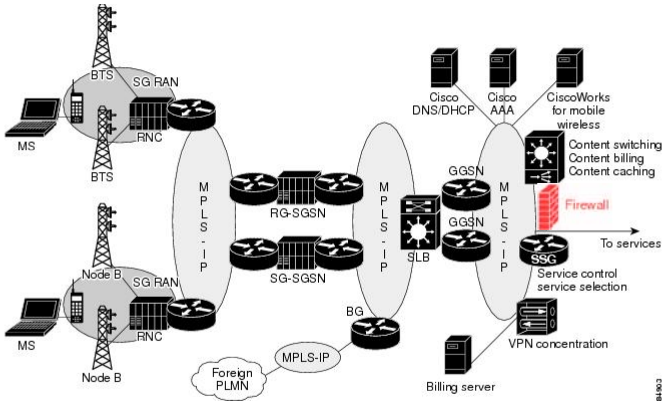
Motivation

- Cellular provider’s network policies are designed to fairly share limited resources and provide security
- These policies are mostly opaque to users, however, they directly impact the performance, energy, and security
- This work seeks to use measurements of cellular networks to infer cellular provider’s policies

Definition

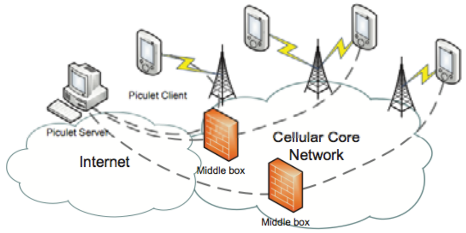
- *Middlebox*: a networking device that transforms, inspects, filters, or otherwise manipulates traffic for purposes other than packet forwarding
- Examples: NAT, firewall, IDS

Cellular Infrastructure



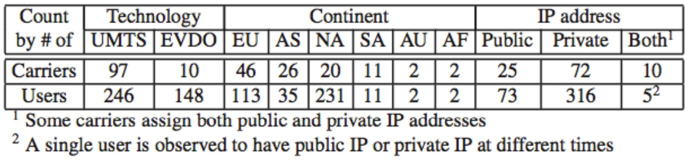
- Middleboxes are deployed near the GGSN (Gateway GPRS Support Nodes)

NetPiculet System



- NetPiculet runs on client mobile devices and the Piculet server
- Server’s upstream provider has no restrictive policies that interfere with experiments
- Clint runs tests in parallel, which finish in 10s
- Except TCP timeout test, which runs as background service

Carriers and Users Sampled



Count	Technology		Continent						IP address		
by # of	UMTS	EVDO	EU	AS	NA	SA	AU	AF	Public	Private	Both[1]
Carriers	97	10	46	26	20	11	2	2	25	72	10
Users	246	148	113	35	231	11	2	2	73	316	5[2]

[1] Some carriers assign both public and private IP addresses

[2] A single user is observed to have public IP or private IP at different times

- Client software available on Android Market
- Attracted users by provided useful network information (e.g., will this P2P app run on this network)
- 393 unique users revealed information on 107 carriers

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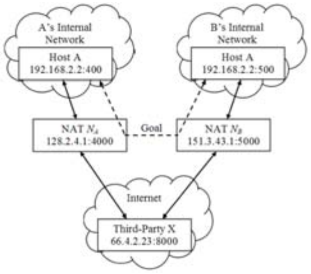
NAT Traversal



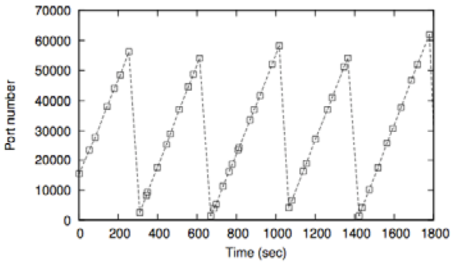
- NAT traversal is required by P2P applications
- Goal is to establish a TCP connection between A and B
- Many hacks exist, dependent mostly on what mapping method each NAT is using
  - When does the NAT assign a new external endpoint (e.g., per source or per connection)?
  - How is the external endpoint port number chosen (e.g., incremental or random)?

NAT Mapping Results

NAT Mapping	# carriers
Independent	30
Address and Port$_1$	15
Connection$_R$	19
Connection$_T$	5
Address and Port$_T$ & Connection$_T$	3
Total	72

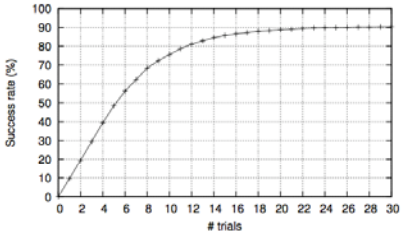
- NAT Mapping methods
  - Independent: external endpoint remains same for all connections
  - Address and Port: external endpoint changes when destination endpoint changes
  - Connection: external endpoint changes for each new connection
- Meaning of subscripts
  - 1: external port is incremented by 1
  - R: external port is random
  - T: described on next slide…

Time-dependent NAT mapping

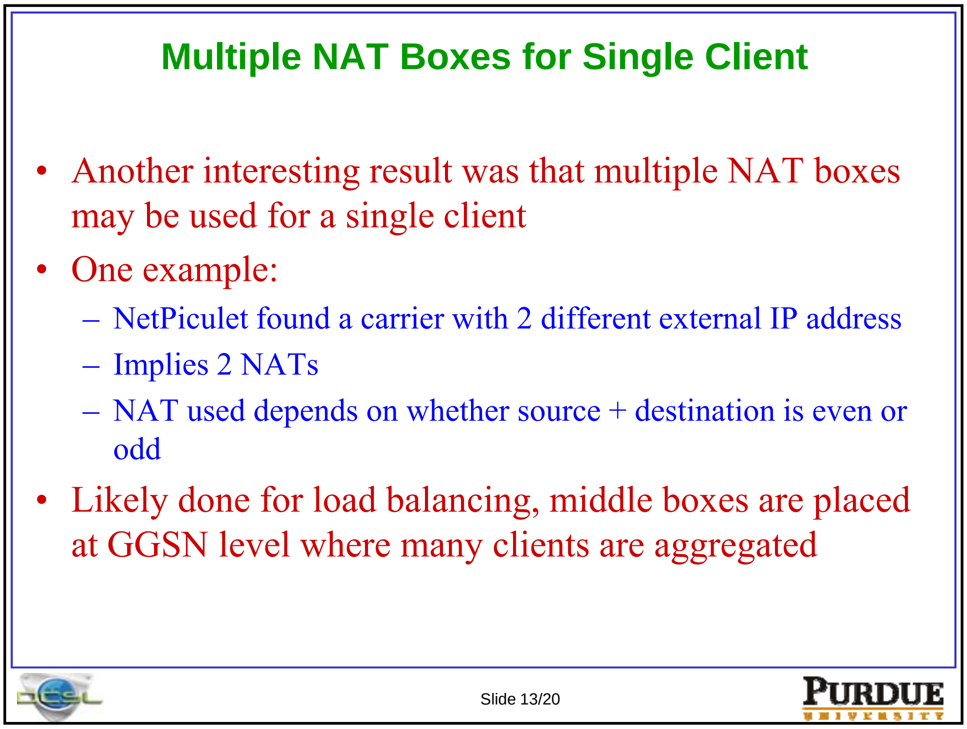


- 8 carriers where initially classified as Connection$_R$ or Address and Port$_1$
- Closer inspection showed they were time dependent
- This type of NAT has not been encountered in NAT traversal literature

Traversing Time-Dependent NAT

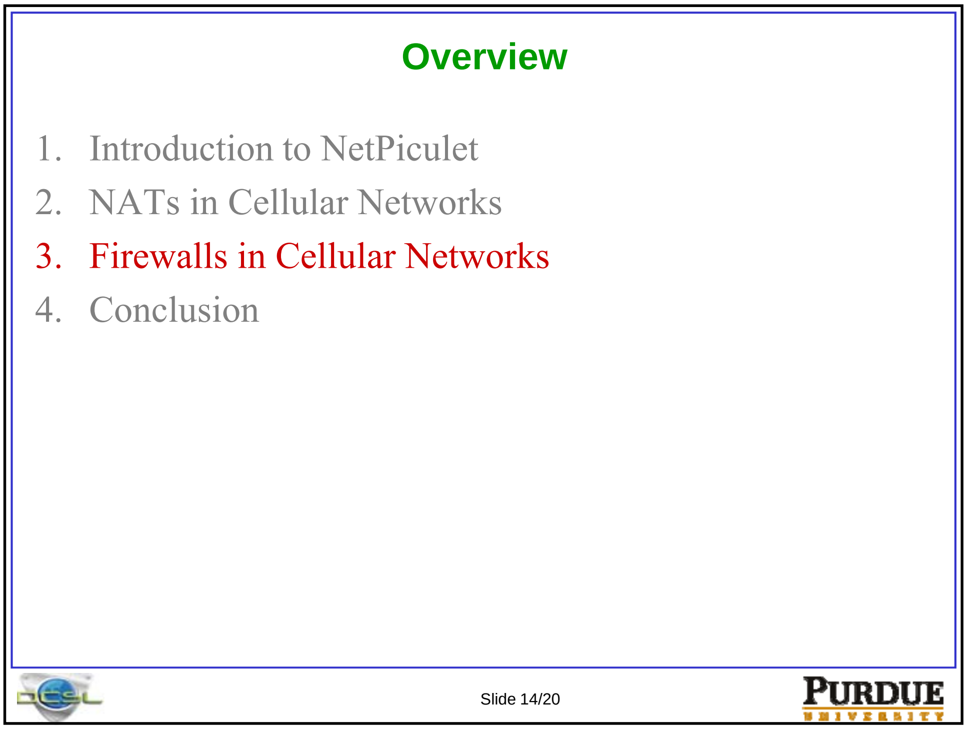


- State-of-the-art for random endpoint mapping
  - NATBlaster has A send 439 SYN packets
  - B sends SYN+ACK packets to random NAT$_A$ ports
  - Birthday paradox gives B a 95% chance of succeeding by its 440th attempt
- However, if we know mapping is time dependent we can use lighter weight approach
- Client B makes guesses of NAT$_A$ endpoint port in range [B_S+δ-n, B_S+δ+n]
  - B_S = b's external port discovered by server S
  - δ = port number increase (predicated by server S)
  - n = 15



Multiple NAT Boxes for Single Client

- Another interesting result was that multiple NAT boxes may be used for a single client
- One example:
  - NetPiculet found a carrier with 2 different external IP address
  - Implies 2 NATs
  - NAT used depends on whether source + destination is even or odd
- Likely done for load balancing, middle boxes are placed at GGSN level where many clients are aggregated



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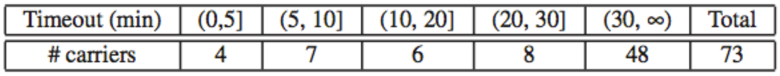
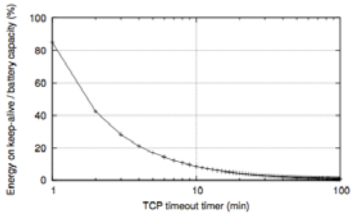
Testing TCP Connection Timeout



Timeout (min)	(0,5]	(5, 10]	(10, 20]	(20, 30]	(30, ∞)	Total
# carriers	4	7	6	8	48	73

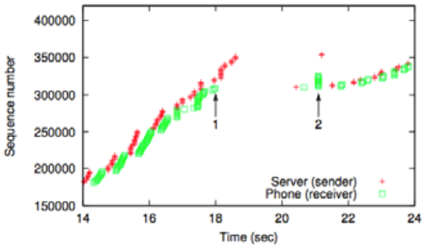
- NetPiculet opens multiple parallel connections without keep-alive option
- Each connection used to send message to server after specific amount of time
- 5, 10, 20, 30 minute idle time intervals tested

Energy Impact of TCP Connection Timeout



- Example:
  - MSN Talk needs to keep TCP connection open for long time
  - One major carrier had timeout of 255 seconds
  - MSN Talk was forced to re-establish connection, more delay and energy cost than sending keep-alive message
- Found 17% of battery capacity spent on keep-alive messages over one day for timeouts of less than 5 minutes
- There is trade off between client energy and provider’s firewall capacity
- One solution is push service framework

Evidence of Packet Buffering



- Major US carrier was found to buffer packets for over 1 hour
- Packet buffering at the firewall may be used for deep-packet inspection
- Prevents TCP fast retransmission
- In figure
  - Server packet lost at time 1
  - Server keeps sending to fill congestion window
  - Phone never sends duplicate acks that would normally trigger fast retransmission
  - Eventually server times out and retransmits the lost packet, at which time (2) the firewall releases all of the buffered packets

Impact of Packet Buffering

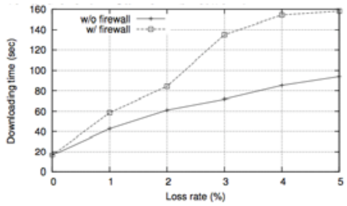


Figure 8: The average downloading time for 1MB file under different loss rates.

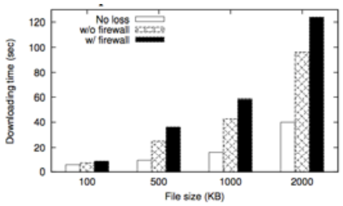


Figure 9: The firewall impact on downloading time for different file size under 1% loss rate.

- Packet buffering is more costly in cellular network because loss rates can be higher than in wireline networks
- Figure 8 shows that buffering increase download time of 1 MB file 50% for a loss rate of just 1%
- Figure 9 shows less impact (only 22% increase) for small 100KB files
- Recent study points out that TCP-based streaming applications that send large amounts of data contribute to majority of smartphone traffic
- Cellular radio stays in high power state during entire download process

Other Firewall Study Findings

- 4 of 60 cellular networks allow IP spoofing, which can make hosts vulnerable to scanning and battery draining attacks even though they are behind the firewall and NAT
- 11 of 73 carriers set TCP timeout to less than 10 minutes, based on study 30 minutes is recommended
- TCP out-of-order buffering behavior in come firewalls is causing unexpected interaction with common TCP behavior defined in TCP specifications

Conclusion

- NetPiculet approach to collecting results: build a tool that users want to use and mine the data (contact HRPP first)
- Cellular network middleboxes impact performance, energy, and security of client applications
- Found unusual NAT and firewall configurations, cellular providers could implement changes to improve user experience