On Cellular Botnets: Measuring the Impact of Malicious Devices on a Cellular Network Core

Patrick Traynor et. al

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Outline

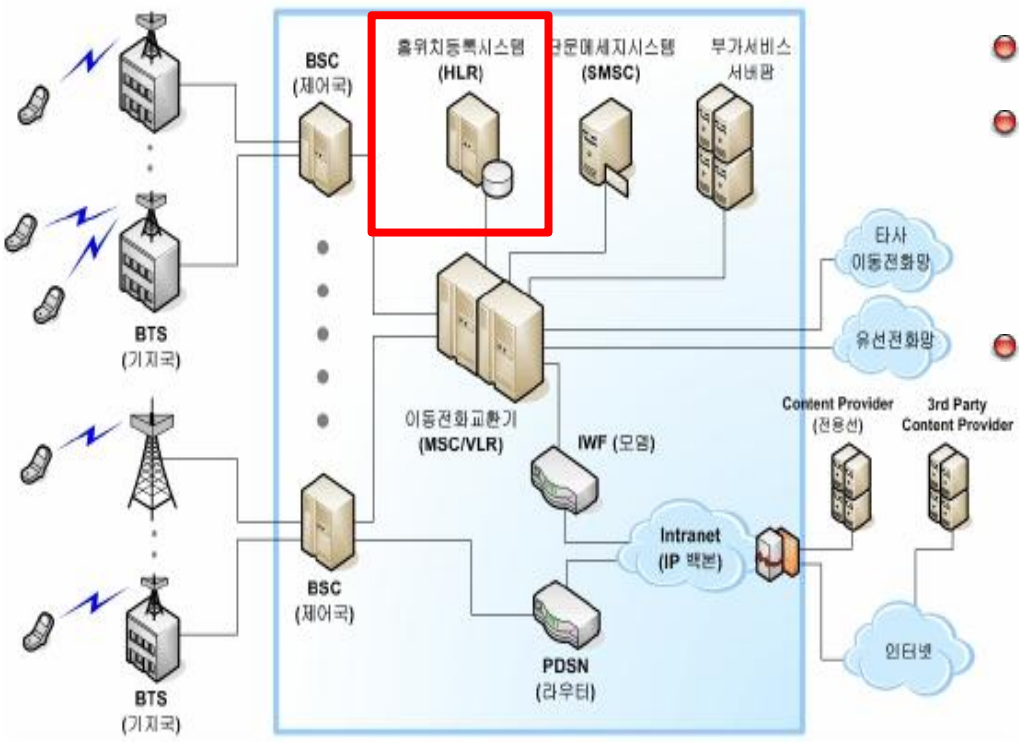
- Introduction
- Attack Overview
- Characterizing HLR Performance
- Profiling Network Behavior
- Attack Characterization
- Avoiding Wireless Bottlenecks
- Command and Control from a botmaster
- Attack Mitigation
- Conclusion

Introduction(1/5)

- **Bot**
  - Short for robots
  - Programs which run autonomously
  - Under the control of a human operator commonly known as a botmaster
- **Botnet**
  - Networks of infected bots
  - Distributed Denial of Service(DDos)
  - Installing Adware
  - Spamming

Introduction(2/5)

- **Cellular Systems – GSM**



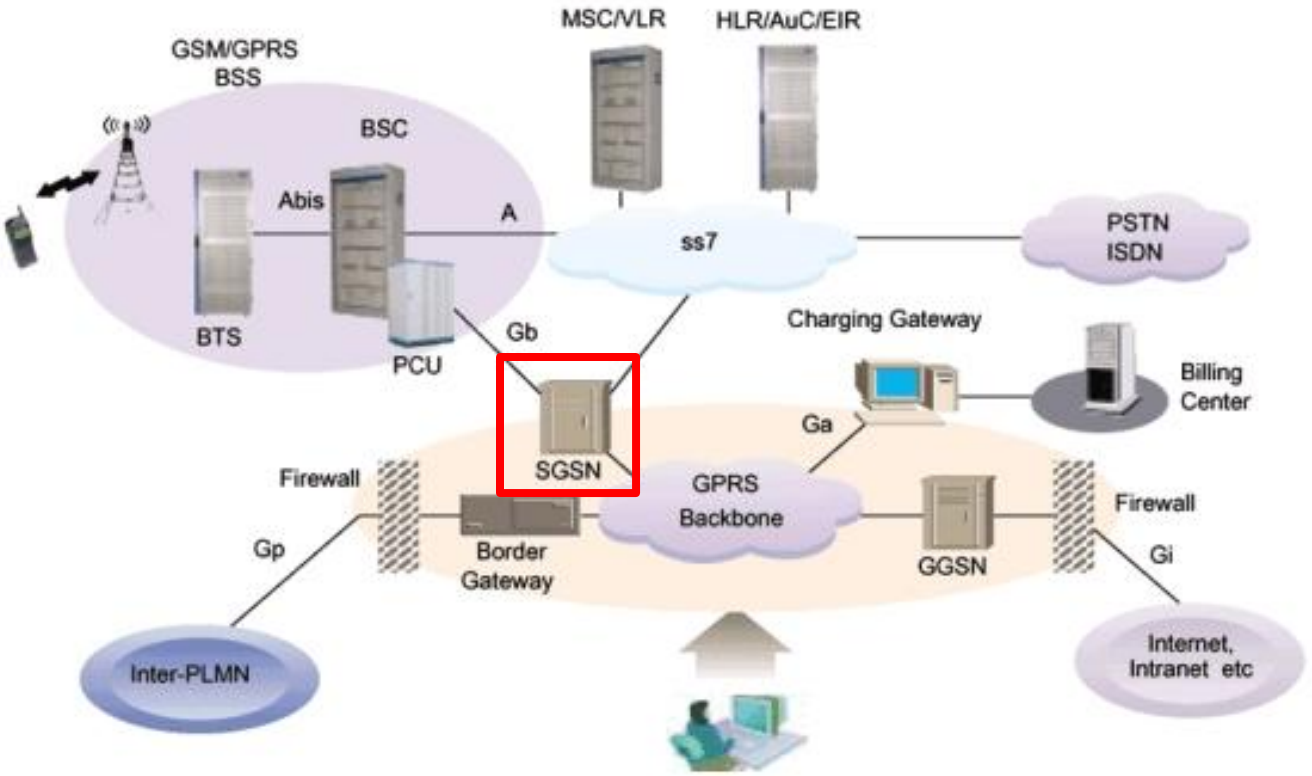
- Mobile Station(MS)
- Base Station Subsystem(BSS)
  - Base Tranceiver Station(BTS)
  - Base Station Controller(BSC)
- Network Subsystem
  - Mobile Switching Center(MSC)
  - **Home Location Register(HLR)**
  - Visitor Location Register(VLR)

Introduction(3/5)

- **Home Location Register(HLR)**
  - Heart of a cellular network
  - Central database that contains details of each mobile phone subscriber that is authorized to use the GSM core network
  - Keeps track of each user's location
  - Manages the power status of the mobile phones
  - Provides the subscribers information

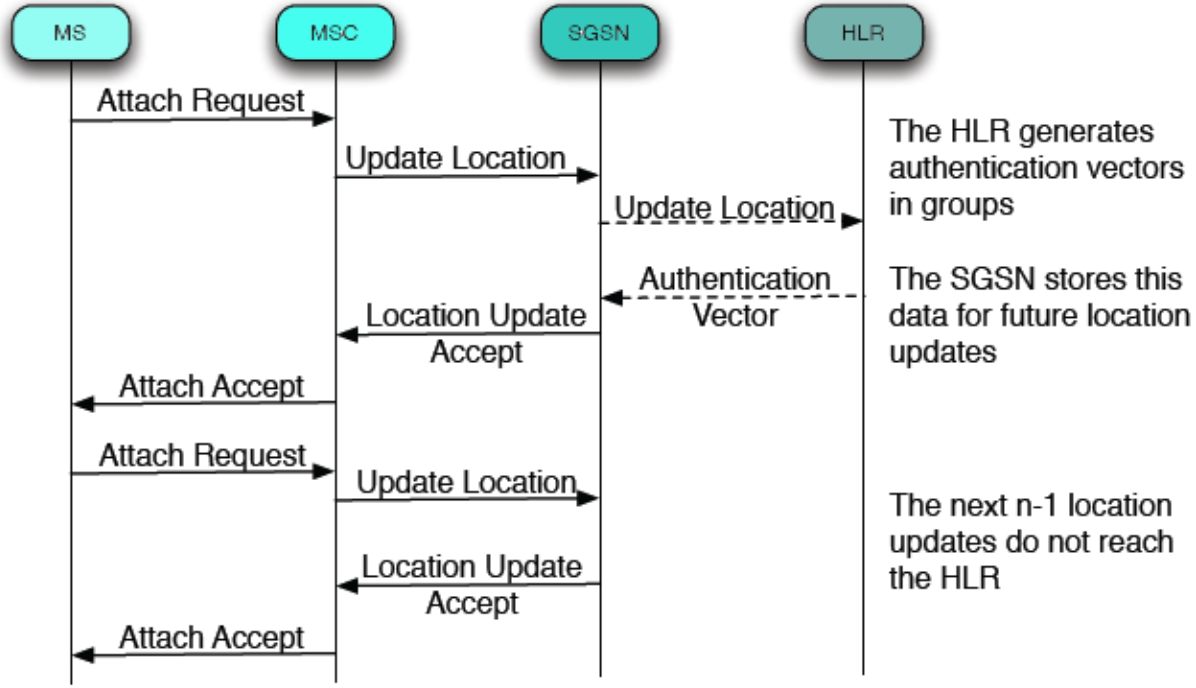
Introduction(4/5)

- **Cellular Systems – GPRS**
  - Upgrade GSM



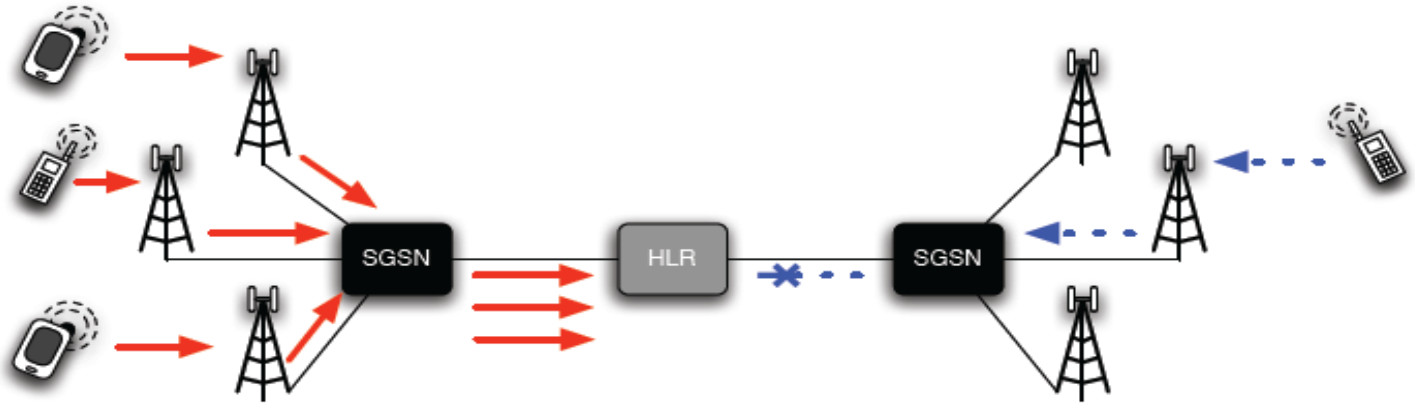
Introduction(5/5)

- **Serving GPRS Support Node(SGSN)**
  - Deliveries of data packets from and to the mobile stations within its geographical service area
  - Get the user's information from HLR



Attack Overview

- **DoS attacks using selected service request type on the Home Location Register(HLR)**



  - Failure of an HLR can cause all users serviced by this database to be denied service
- **Different from the Dos attacks observed on the Internet**
  - Mobile devices transmit only specific types of messages
  - Unnecessary traffic or side effects are not generated

Characterizing HLR Performance(1/2)

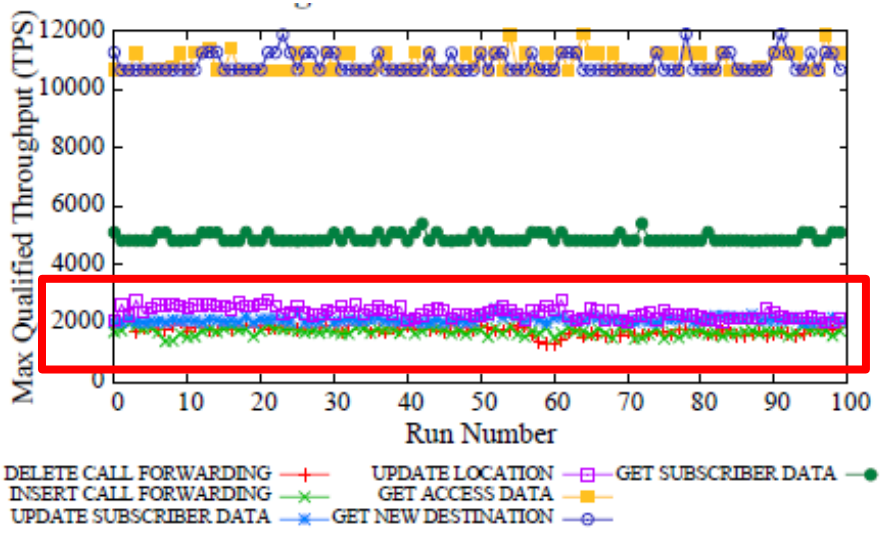
- **Using the Telecom One(TM1)**
  - First database benchmark designed for telecommunication applications
  - Simulates a typical Home Location Register (HLR) database used by a mobile carrier
  - Reducing the effort needed for an adversary to effectively render an HLR unavailable

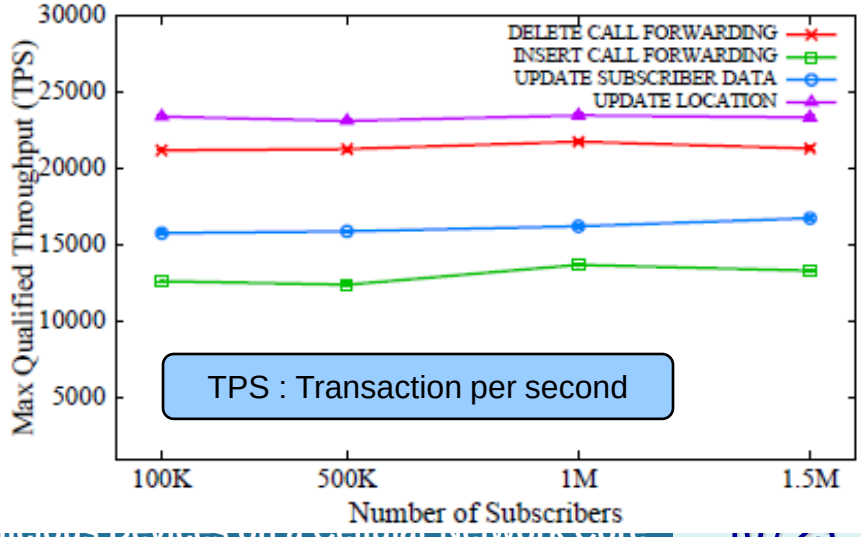
Characterizing HLR Performance(2/2)

- **Simulate normal traffic by providing a "Default Mix" of read and write operations**

Transaction	Type	Default Mix
get_subscriber_data	r	35%
get_new_destination	r	10%
get_access_data	r	35%
update_subscriber_data	w	2%
update_location	w	14%
insert_call_forwarding	rw	2%
delete_call_forwarding	rw	2%

80%



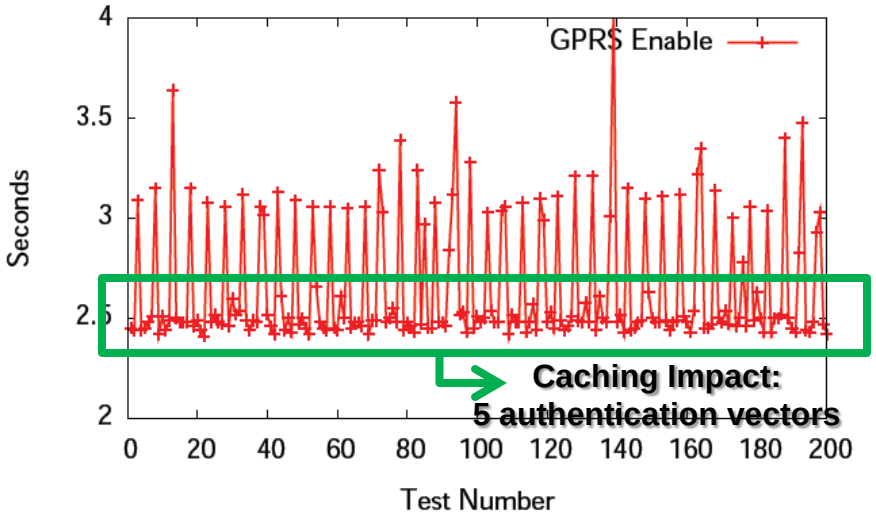


Profiling Network Behavior (1/4)

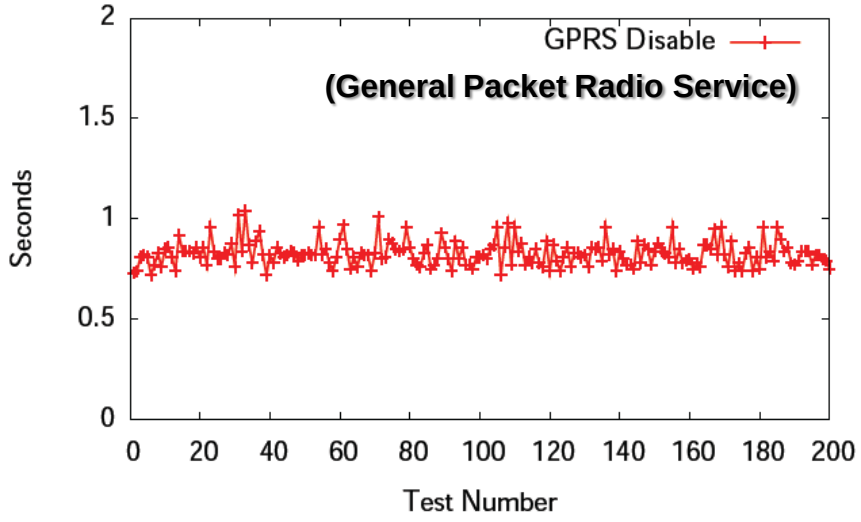
- **Profiling network behavior from an attack perspective**
  - Write-based service requests more expensive than read-based service requests
  - Reconcile the differences between simulations and reality
  - Consult standards documents to verify discrepancies in expected and observed behavior
- **Measuring network behavior**
  - Injected and measured service requests representing each of the four write-based meta-commands on live cellular network
  - Test phone: Nokia 9500 running Symbian Series 80
  - Each AT command was executed a total of 200 times during low traffics with a two second delay between the sequential execution of commands

Profiling Network Behavior (2/4)

- **Update Location**
  - Operation to keep track of each user's location as a device moves between two base stations or turn on/off
  - All location update operations require "device authentication"
  - The caching of authentication data on a real network: making attacks using the update_location meta-command difficult



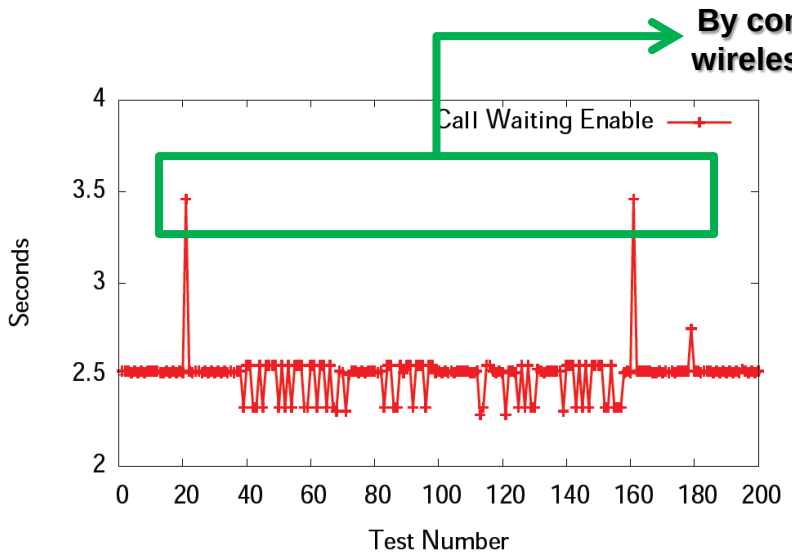
Response times for location updates via the GPRS attach AT command



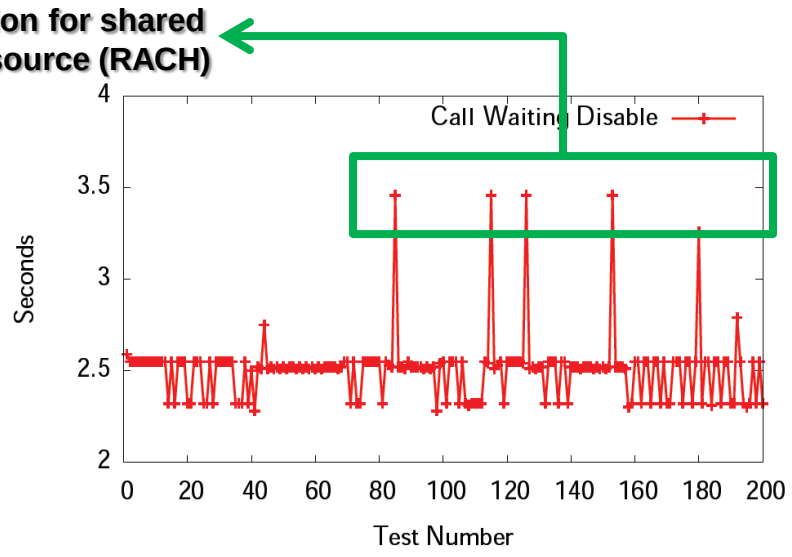
Response times for location updates via the GPRS detach AT command

Profiling Network Behavior (3/4)

- **Update Subscriber Data**
  - Activation, deactivation or modification of the parameters of many services requires the HLR to modify a number of fields
  - Ex. Call Waiting, Call Barring, Modify PDP(Packet Data Protocol) Context
  - All Call Waiting enable requests are directed to the HLR



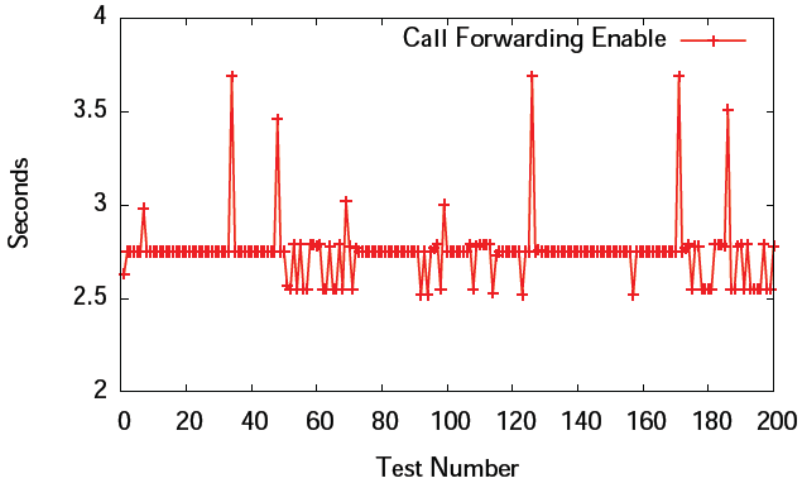
Response times for CW enable request



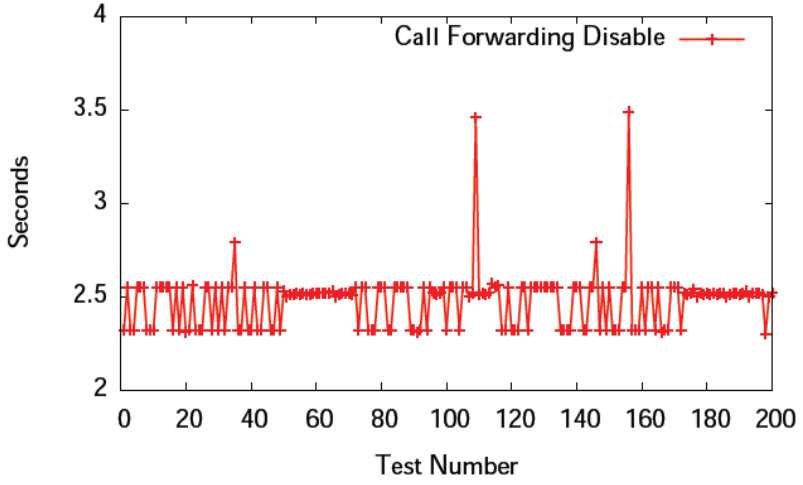
Response times for CW disable request

Profiling Network Behavior (4/4)

- **Insert/Delete Call Forwarding**
  - Redirecting incoming phone calls to other devices
  - The activation and deactivation of this service requires a single exchange with the HLR. Insert call forwarding performs additional checks and an extra database read
  - A good candidate for attack traffic: more expensive for the HLR compared to Update Subscriber Data



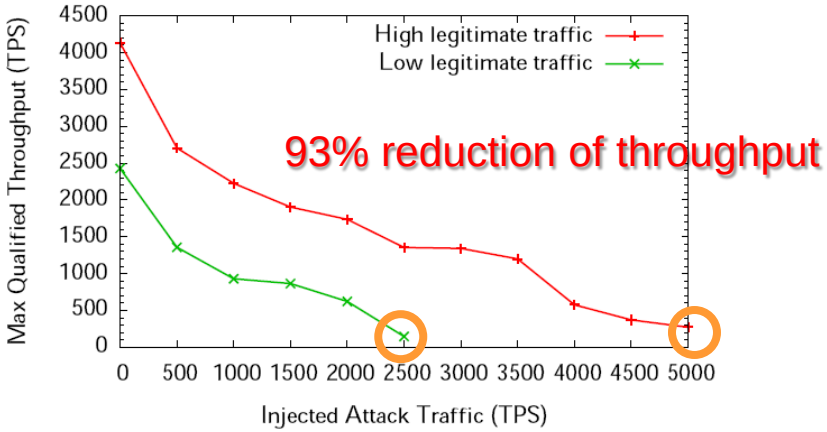
Response times for CF enable request



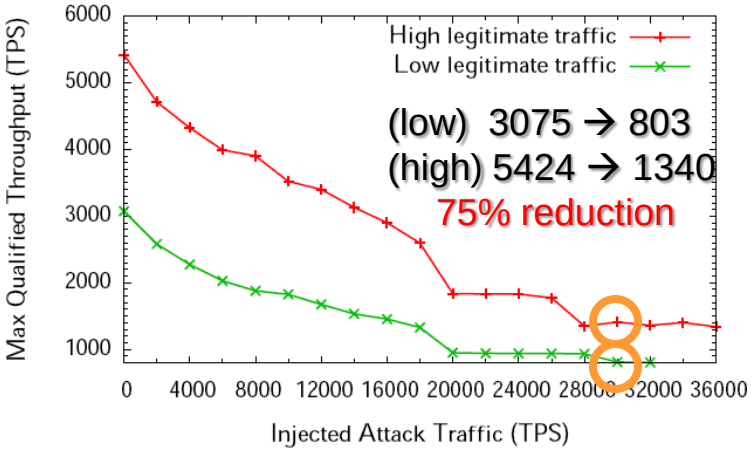
Response times for CF disable request

Attack Characterization (1/2)

- The optimum meta-command to attack HLR: insert_call_forwarding
- The number of requests (or infected devices) needed to degrade the HLRs throughput beyond a certain point to cause widespread outages
  - Modeling attacks by modifying TM1's client code (multi-threaded)
  - (low traffic) 2427 mix TPS → 146 mix TPS at attack rate of 2500 icf TPS
  - (high traffic) 4132 mix TPS → 274 mix TPS at attack rate of 5000 icf TPS



HLR running MySQL
supporting one million users



HLR running SolidDB
supporting one million users

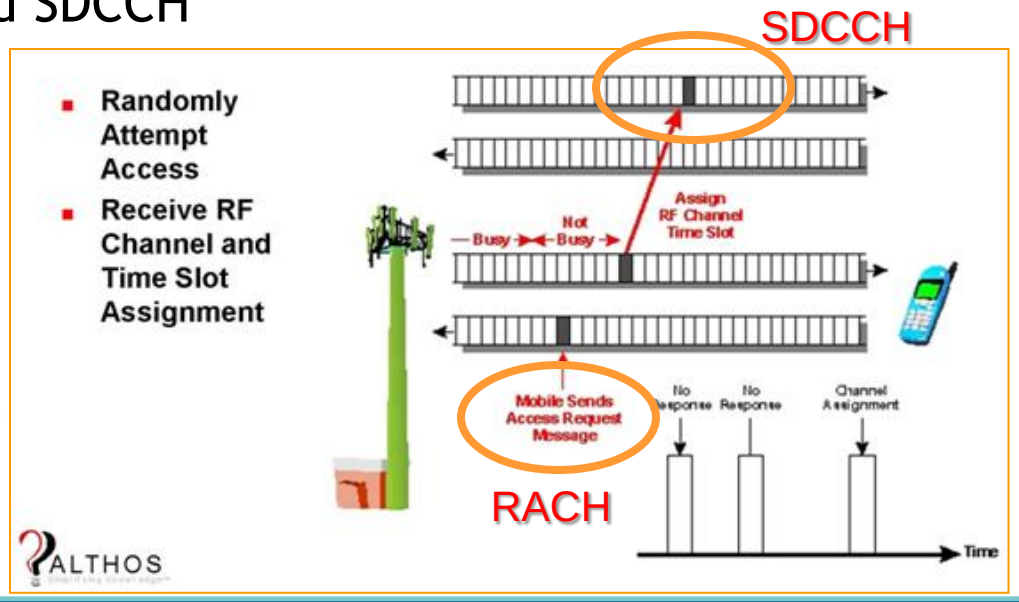
Attack Characterization (2/2)

- The number of devices an adversary requires to successfully launch an attack against an HLR
  - 4.7 second wait between the successful transmission of AT commands
  - HLR running the MySQL database under normal conditions
  - (low traffic) 11,750 infected phones
  - (high traffic) 23,500 infected phones
  - Assuming that each of these HLRs service one million users, only 1.2% and 2.4% rates of infection
  - 141,000, or an infection rate of 14.1% on an HLR running SolidDB

Avoiding Wireless Bottlenecks (1/3)

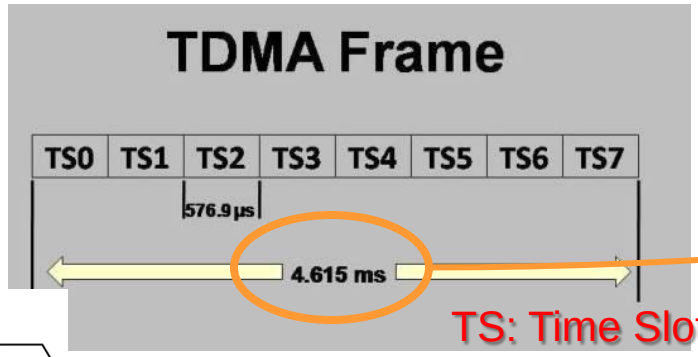
- With a realistic characterization of an attack on the wired portion of a cellular network, a number of obstacles to the successful execution of such an attack exist: wireless bottlenecks
  - GSM multiplexes traffic on a single frequency through the use of TDMA (time division multiple access): incurring collision
  - Therefore, Considering the limited capacity of two channels: RACH and SDCCH

Reference slide from "Introduction to GSM, 2nd ed"



Avoiding Wireless Bottlenecks (2/3)

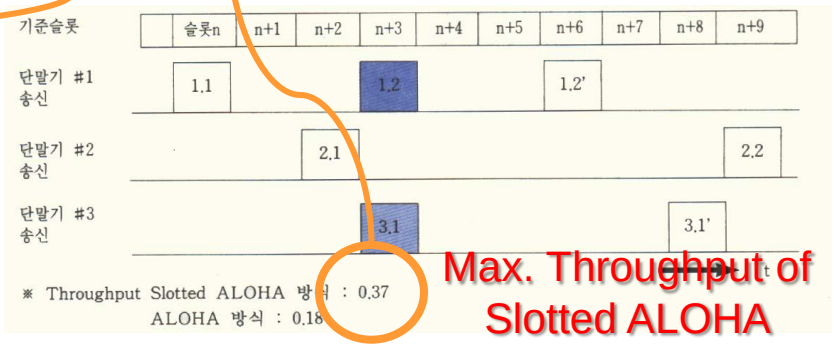
- RACH(Random Access CHannel) Capacity



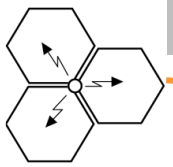
TS: Time Slot

Max # of Access Request:

(1000/4.615) * 0.37 ≒ 80



Max. Throughput of Slotted ALOHA



$$\alpha = \frac{5000 \text{ messages/sec}}{3 \text{ sectors/cell} * 80 \text{ RACH transmissions/sec}}$$

$$\alpha = 21 \text{ base stations}$$

→ Botnets must be well distributed over at least 23 base stations to send 5000 msg/sec

- If 3 areas per Base stations, 200 base stations per MSC, 10 MSCs per HLR , then network wide RACH capacity = 481,074 commands per second

Avoiding Wireless Bottlenecks (3/3)

- SDCCH(Standalone Dedicated Control Channels) Limitations
  - Sectors in a GSM network typically allocate 8 or 12 SDCCHs
  - Hold time of SDCCH channel based on experiment = 2.7 sec

$$\alpha = \frac{msgs/sec}{sectors * SDCCHs * \rho_{SDCCH}}$$

1 / 2.7

$$\alpha = \frac{5,000}{3 * 12 * 0.37} = 375 \text{ base stations}$$

  - 375 base stations will be needed to handle the air interface load of an attack: 14 or 13 botnets at most in a base station
  - Coordination of thousands of compromised phones and avoiding contention when high concentrations of such devices are present must therefore be considered

Command and Control from a botmaster

- Means of communicating with and coordinating the actions of compromised hosts to avoid the wireless bottlenecks
  - Internet Coordination: using number of Internet-capable phone
    - Reapplying current techniques. Ex. Polling a known communication channel, Peer-to-peer communication with time triggered techniques
    - Disadv: constrained by the architecture of the network (network bottelneck). easily identified and blocked by mobile operator
  - Local Wireless Coordination: using bluetooth or 802.11
    - Adv: no bottleneck, no monitoring
    - Disadv: communication range. Increasing the density of infected devices will increase contention for local resources
  - Indirect Local Coordination: modifying GSM back off algorithm

Attack Mitigation

- Meaningless defenses
  - Database replication
    - Useless against a large-scale attack
    - In particular, an attack targeting a large portion of the HLRs
  - Centrally located, highly capable HLRs
    - attacks may in fact be more likely to succeed
- Possible (useful) defenses
  - Filtering: blocking some functions
    - Ex: insert call forwarding is not critical to the basic functioning of the network
  - Call gapping: blocking calls for a period of time, periodically
    - a load control method for throttling telephone traffic on a telephone network when the network is overloaded
- Challenges: developing mechanisms intelligent enough to respond to a more dynamic attacks

Conclusion (1/2)

- This paper demonstrated that relatively small botnets pose significant threats to the availability of mobile network
  - Considered mobile network architecture, functions of HLR, wireless bottlenecks, command and control
  - Possible threat in near future
    - By mainly smart phones which lack relatively basic security mechanism compared to feature phones

News about security threats against smart phone

손 안의 PC '스마트 폰', 보안은?

모바일 악성코드 30개국 800건 발생…보안 대책 시급

2010년 03월 31일 (수) 21:36:16

개방형OS 앱스토어 '보안이 문제'

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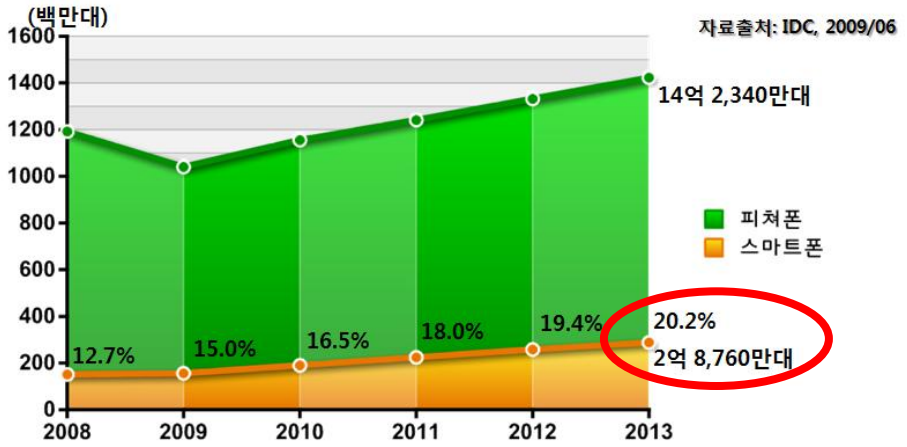
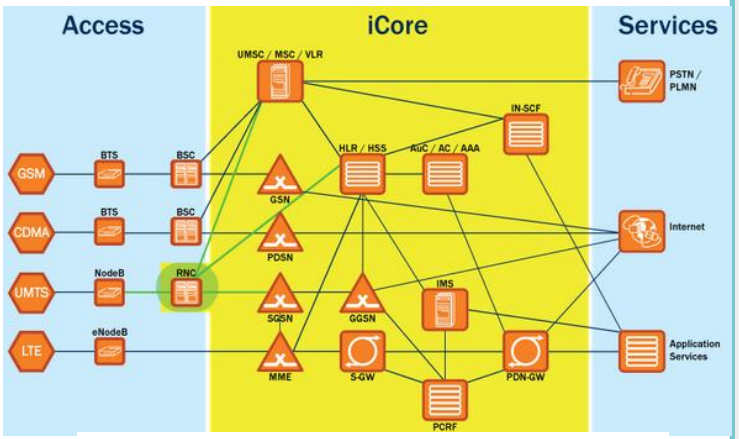


Conclusion (2/2)

- Attacks against CDMA ?
  - Similar properties of HLR
    - Authentication Mechanism is slightly different: no SIM card in CDMA
    - But features for attacks seem to be similar to those of GSM: database, structure of core network and call forwarding service
  - Less limitation of wireless bottlenecks
    - CDMA has more network capacity
    - Therefore, more compromised phones can be located within same area



Mobile Network Architecture (2G, 3G, 4G)

Question or Comment