CS259D: Data Mining for CyberSecurity

Botnet

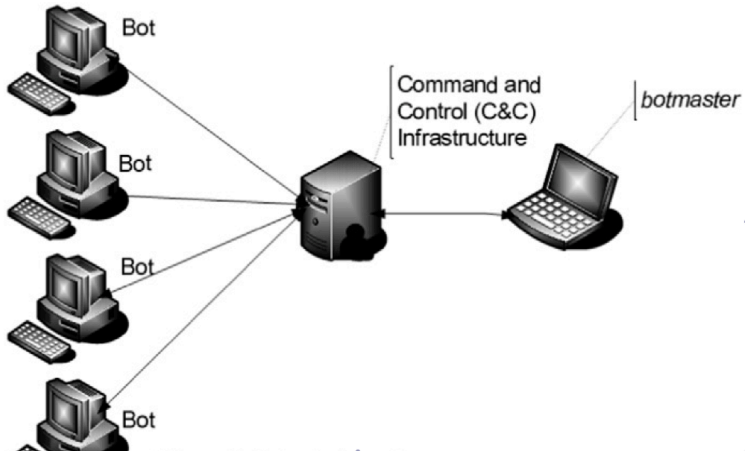
- Networks of machines compromised by malware
- Estimated 16-25% of computers on Internet part of a botnet
  - Botnet Rustock has over 1 million bots
  - Botnet Storm one of "world's top super computers"
- Applications
  - Information and identity theft
  - Distributed denial of service (DDoS)
  - Software piracy
  - Spamming/Phishing
    - Almost 80% of all email traffic
    - Example: Grum, Cutwail, Rustock
  - Underground economy
    - 10,000 bots for $15
- Scale of damage (cf. International Telecommunication Union)
  - $13.2B direct damages to global economy in 2006
  - $67.2B in direct and indirect damages to US businesses in 2005
  - Global cost of spam in 2007: $100B global, $35B in US

Starting point

- Internet Relay Chat (IRC)
  - Text-based chat system
  - Organize communications in channels
  - Botnets to control interactions in IRC chat rooms
    - Interpret simple commands
    - Provide administration support
    - Offer simple games/services
    - Retrieve information: OS, logins, emails, etc.
  - First IRC bot: Eggdrop, 1993

Botnet components

- Zombies
  - High transmission rates
  - Low levels of security
  - Distant locations
  - Mostly MS Windows



Botnet lifecycle

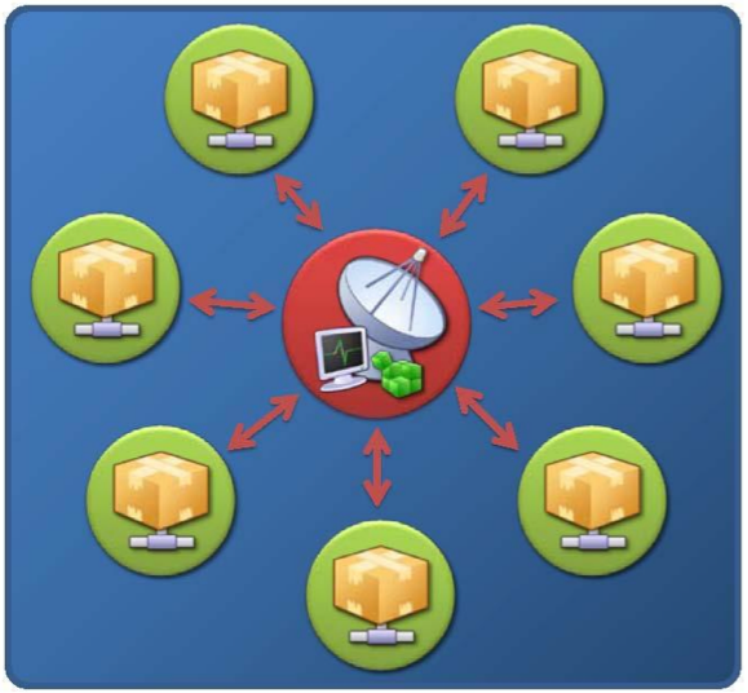
- Initial infection
  - infected websites, email attachments, removable media, etc.
- Secondary injection
  - Host downloads & runs binaries, becomes a bot
  - FTP, HTTP, or P2P
- Connection or Rally
  - process of establishing connection with C&C
  - Happens every time the host is restarted
- Malicious activities
  - More intense message exchange between bot and C&C
- Maintenance and upgrading

Botnet C&C topologies

- Star
- Multi-server
- Hierarchical
- Random

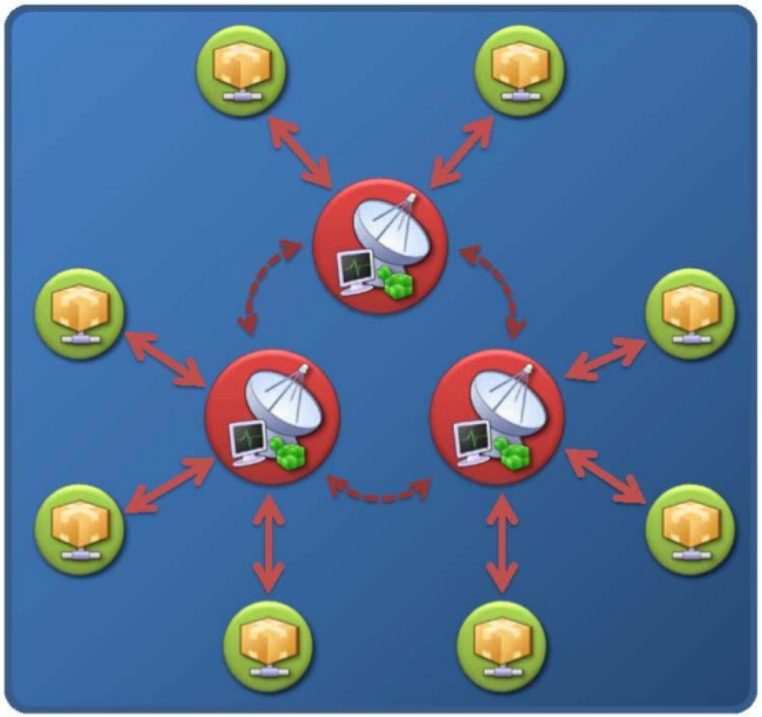
Star C&C topology

- Centralized C&C communicate with all bots
- Protocols used:
  - IRC
    - C&C functionality of SDBot, GTBot, Agobot still in use
      - Source code published by author
  - HTTP
    - Blend in with normal user traffic
    - Do-it-yourself kits
  - Instant-Messaging (IM) protocols
    - ICQ, AIM, MSN Messenger
    - Needs creating one account per bot
- Pro:
  - Speed of Control
- Con:
  - Single point of failure



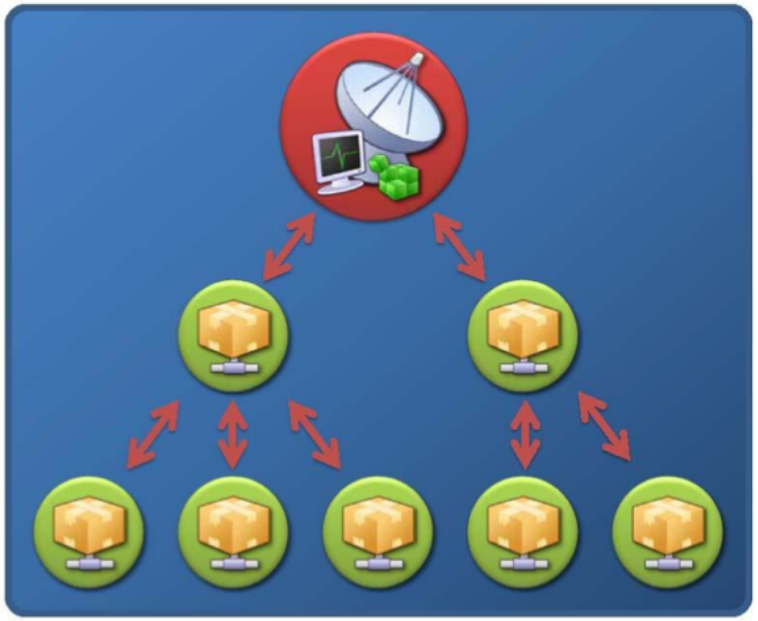
Multi-Server C&C topology

- Extension of Star topology
- C&C servers communicate among themselves
- Pros:
  - No single point of failure
  - Geographical optimization
- Cons:
  - Requires more planning/ effort from the operator



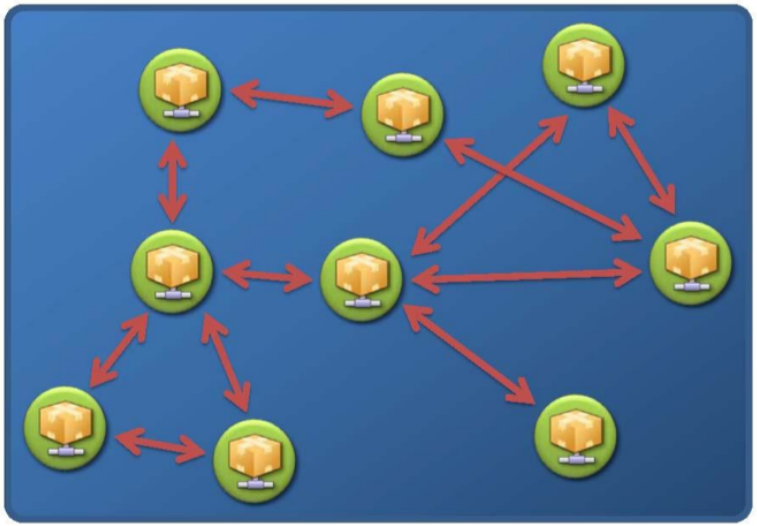
Hierarchical C&C topology

- One group of bots acting as servants
  - Static routable IP addresses
  - Proxy C&C instructions to client bots
- Variant: Hierarchical Kademlia
  - Set of clusters or islands of bots
  - P2P for intra-cluster communication
  - Inter-cluster communication: super bot peers
- Pros:
  - Botnet awareness: Interception of botnet won't enumerate all members, unlikely to reveal C&C
  - Ease of resale
    - Lease/resale sections of botnet to other operators
- Cons:
  - Command latency: Not suitable for real-time activities



Random topology

- No centralized C&C
  - Commands injected by botmaster via any bot by sharing/publishing command files
  - Commands signed as authoritative to avoid takeover
- Future: Skype-based botnets
  - Better blend in with other P2P traffic
- Pros:
  - Highly resilient
- Cons:
  - Command latency
  - Botnet enumeration



Rallying mechanisms

- C&C location resolution
- Static Lists
  - Hard-coded list of IP addresses
  - Can be detected via a feed of botnet IPs
- Fluxing
  - Add resilience
  - Types
    - IP flux
    - Domain flux

IP flux

- Constant changing of IP address information
- Single flux
  - Multiple (100s-1000s) IP addresses associated with a domain name
  - IP addresses registered and de-registered rapidly
    - Round-robin allocation
    - Short Time to Live (TTL) for DNS A records
- Double flux
  - Flux IP address of fully-qualified domain name
  - Flux IP address of DNS server (NS records) used to look up IP address

Domain flux

- Domain wildcarding
- Domain generation algorithms

Domain wildcarding

- Use wildcarding in DNS records
  - Example: *.domain.com
- Useful for spamming/phishing; wildcard information used to
  - Identify victim (e.g., rjhgbrwh.domain.com)
  - Track success

Domain generation algorithms

- Create a dynamic list of FQDN's every day
  - Cryptographic domain names
- Generated FQDN's polled by bot to find C&C
- Example: the worm Conficker.C
  - Generates 50,000 domain names every day
  - Attempts to contact 500
  - 1% chance of update every day if operator registers only 1 domain per day
  - Preventing update requires registering 50,000 new domains every day
- Benefit
  - Domain names generated in volume, with short (typically 1-day) life span
  - Very difficult to investigate/block all possible domain names

Blind proxy redirection

- Add an extra layer of resiliency
- Proxy IP/domain lookup and C&C traffic

Botnet detection: challenges

- Botnet traffic similar to normal traffic
  - Likely encrypted as well
- Botnets evolve rapidly
  - New bots constantly getting added
  - Changing protocols
  - Changing architectures
  - Changing infection models
  - Fast flux hosting

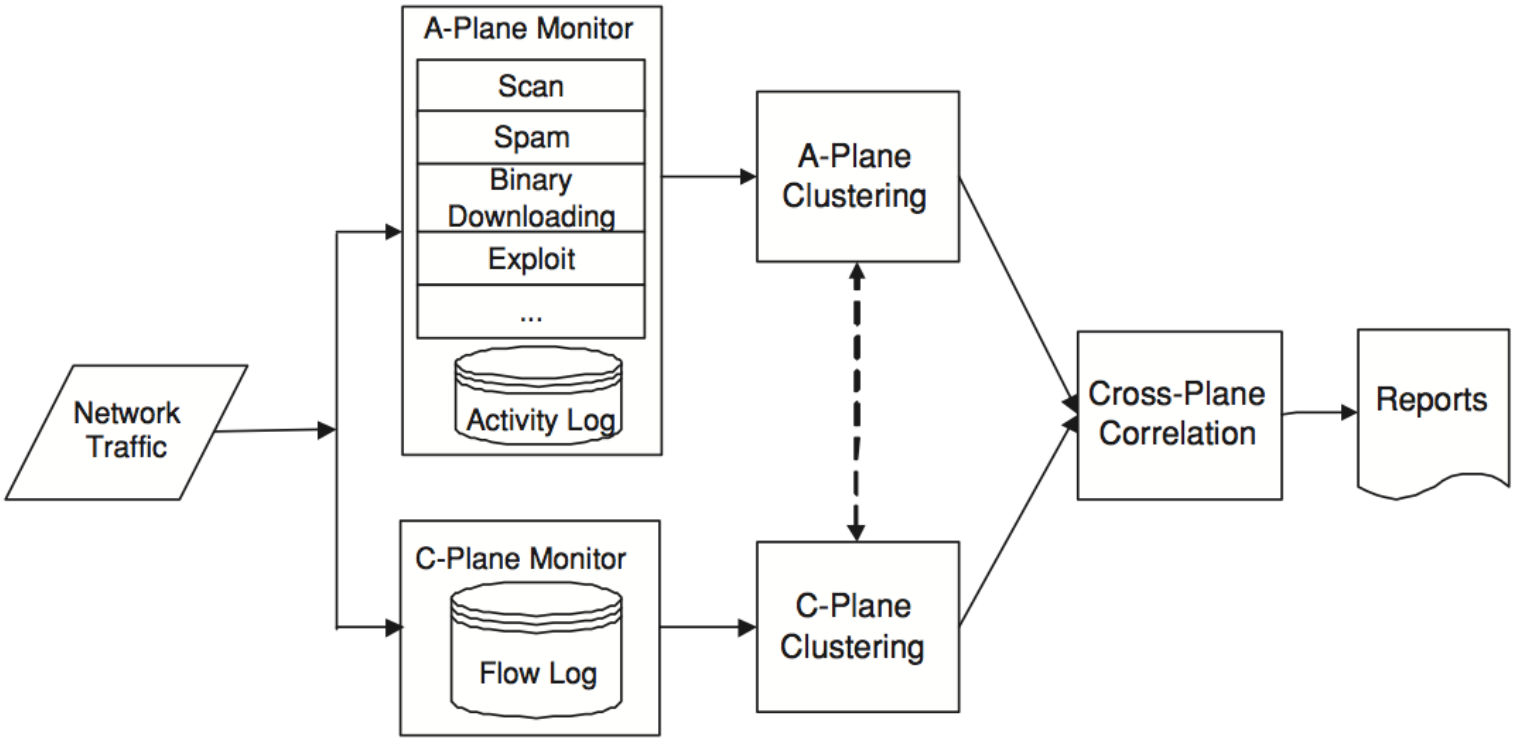
Botnet detection: BotMiner (2008)

- Intrinsic properties of botnets:
  - Bots communicate with C&C servers/peers
    - Centralized, Decentralized, etc.
  - Bots do malicious activities
    - IRC-based botnets
      - 53% of botnet activity related to scan
        - For DDoS or spreading
      - 14.4% related to binary downloading
    - HTTP/P2P-based botnets
      - Mostly for sending spam
  - Bots act a similar/correlated way
    - Otherwise, just a group of unrelated/isolated infections
    - Bots are non-human driven, programmed to perform C&C logic/communications

Botnet detection: BotMiner

- Detection method:
  - Cluster similar communication traffic
    - Who is talking to whom
    - C-plane (C&C communication traffic)
  - Cluster similar malicious traffic
    - Who is doing what
    - A-plane (Activity traffic)
  - Perform cross-cluster correlation
    - Find a coordinated group pattern
- Assumes no a priori knowledge of
  - Botnet's protocol
  - Captured bot binaries (botnet signatures)
  - C&C server names/addresses
  - Content of the C&C communication

BotMiner Archticture

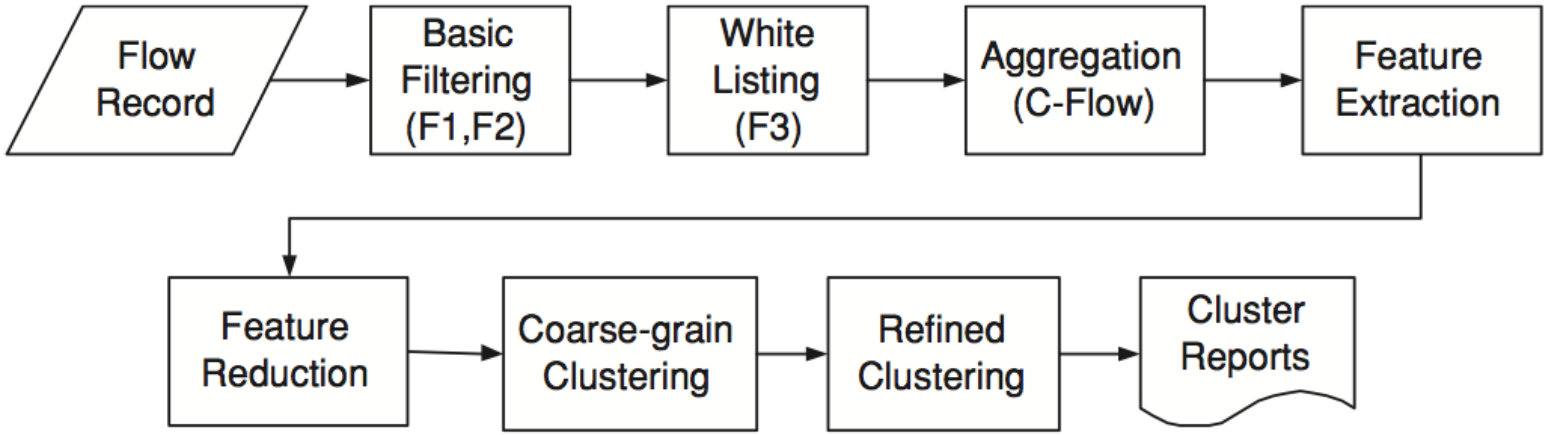


BotMiner: Traffic monitor

- C-plane: captures network flows
  - Who is talking to whom
  - Each record contains the following info:

    Time, duration, source IP & port, destination IP & port, number of packets & bytes transferred in each direction
- A-plane:
  - Who is doing what
  - Analyzes outbound traffic
  - Detects several types of malicious activities
    - Scanning:
    - Spamming:
    - Binary downloads
    - Exploit attempts
  - Based on Snort, with some modifications

BotMiner: C-plane clustering



BotMiner: C-plane clustering

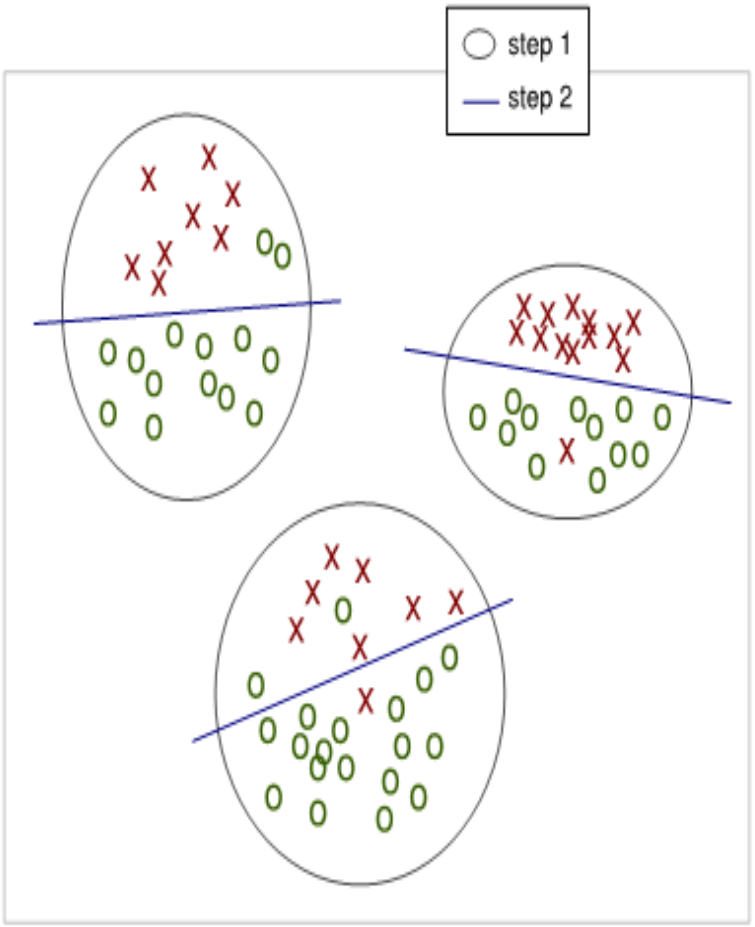
- Find machines with similar communication patterns
- Steps:
  - First two step not critical but help efficiency
    - filter out irrelevant traffic flows, filter out flows that are not completely established, filter out flows with well-known destinations
  - Third step: Given an epoch, aggregate into communication flows (C-flows)
    - C-flow = $\{F_i\}$ where F_i have same protocol (TCP/ UDP), source IP, destination IP & port

C-flow feature extraction

- For each C-flow:
  - Temporal
    - Number of flows per hour (fph)
    - Number of bytes per second (bps)
  - Spatial
    - Number of packets per flow (ppf)
    - Number of bytes per packets (bpp)

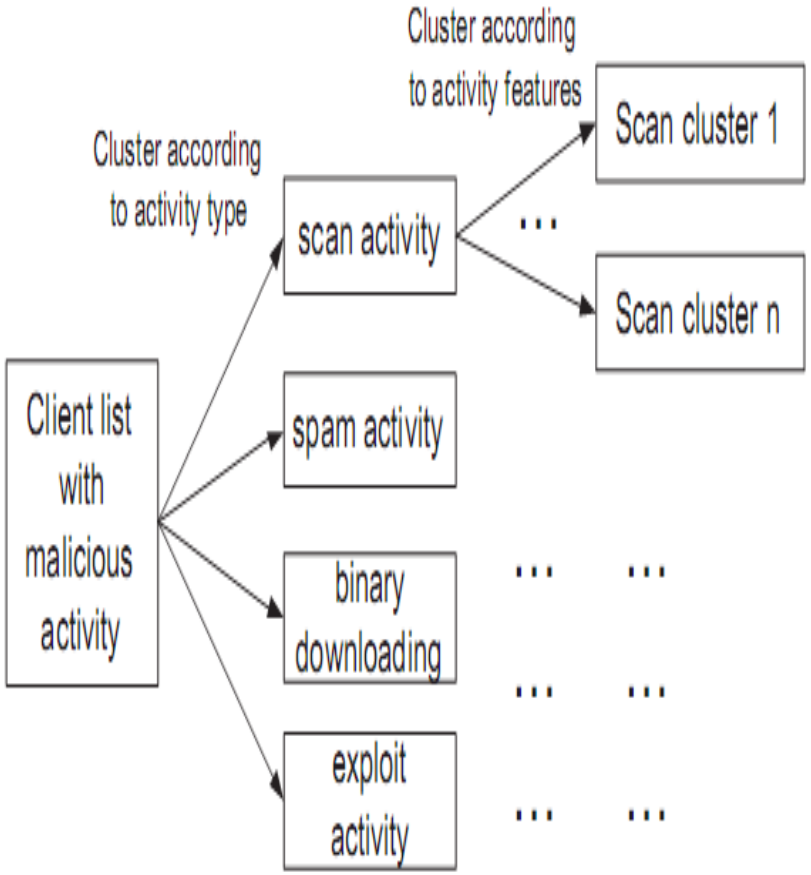
C-plane clustering

- Performed in two step using a variant of k-means
  - Coarse grained clusterir on entire dataset
  - Fine-grained clustering c multiple smaller clusters using all features
- Reduced feature set:
  - Avg, Std-dev of each feature
- Full feature set:
  - 13 bins per feature to approximate their distribution



A-plane Clustering

- Scan activity features
  - Scanning ports
  - Target subnet
- Spam activity features
  - SMTP connection destinations
- Binary download
  - First/random portion/ packet of the binary



BotMiner: Results

Botnet	Number of Bots	Detected?	Clustered Bots	Detection Rate	False Positive Clusters/Hosts	FP Rate
IRC-rbot	4	YES	4	100%	1/2	0.003
IRC-sdbot	4	YES	4	100%	1/2	0.003
IRC-spybot	4	YES	3	75%	1/2	0.003
IRC-N	259	YES	258	99.6%	0	0
HTTP-1	4	YES	4	100%	1/2	0.003
HTTP-2	4	YES	4	100%	1/2	0.003
P2P-Storm	13	YES	13	100%	0	0
P2P-Nugache	82	YES	82	100%	0	0

BotMiner: Limitations

- Evading C-plane monitoring/clustering
  - Randomize individual communication patterns
    - Example: randomize number of packets per flow, number of bytes per packet
- Evading A-plane monitoring/clustering
  - Stealthy malicious activities
    - Scan slowly
- Evading cross-plane analysis
  - Delay the malicious activities (give commands a few days in advance)
- Offline system
  - Prolonged data collection

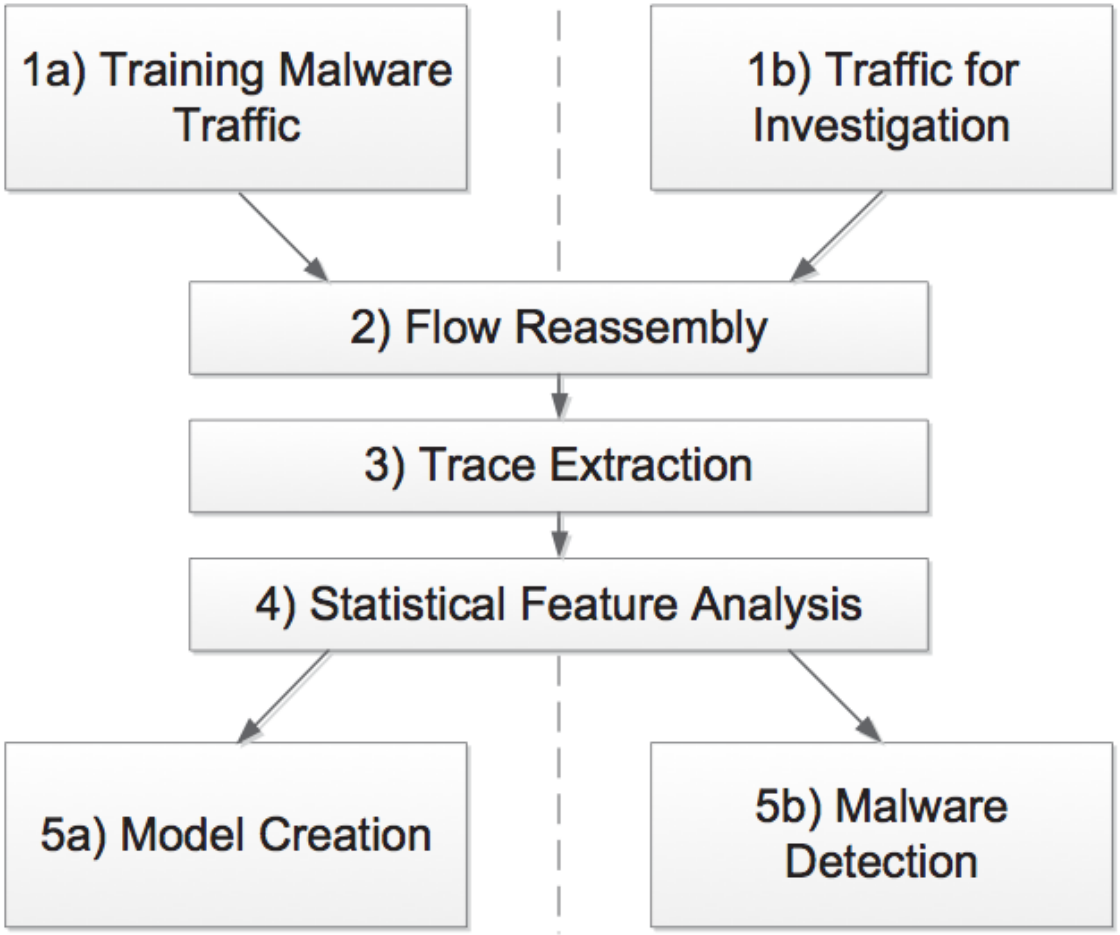
Botnet detection: BotFinder (2012)

- Goals
  - Detect individual bot infections
  - Only rely on network flow
    - Resilient to encryption or obfuscation
    - No need for deep packet inspection
  - Detect stealthy bots stealing data but not spamming
- Observation
  - C&C connections follow regular patterns
  - Run bot binaries in a controlled environment, learn patterns

Botnet detection: BotFinder (2012)

- Observation
  - C&C connections follow regular patterns
  - Bots send similar traffic to C&C
  - Upload information to C&C in similar way
  - Timing patterns of communications with C&C

BotFinder: System



BotFinder: Features

- Average time between the start times of two subsequent flows in the trace
- Average duration of a connection
- Number of bytes transferred on average to the source
- Number of bytes transferred on average to the destination
- Fourier Transform over the flow start times

BotFinder: Model Creation and Mathing

- Cluster each feature separately
  - Malware features uncorrelated
- Matching: Match each feature of the trace against the corresponding model's cluster

Results

Malware Family	BOTFINDER Detection	BOTFINDER False Positives	*BotHunter* Detection
Banbra	100%	0	24%
Bifrose	49%	0	0%
Blackenergy	85%	2	21%
Dedler	63%	0	n/a
Pushdo	81%	0	11%
Sasfis	87%	1	0%

References

- Botnet Communication Topologies

(https://www.damballa.com/downloads/r_pubs/WP_Botnet_Communications_Primer.pdf)

- BotMiner: Clustering Analysis of Network Traffic for Protocol- and Structure-Independent Botnet Detection

- BotFinder: Finding Bots in Network Traffic Without Deep Packet Inspection