Traffic analyzer for differentiating BitTorrent handshake failures from port-scans

Kamran Riaz Khan
Microsoft Corporation
Redmond, WA, USA
<kakhan@microsoft.com>

Affan A. Syed
SysNet Lab, NUCES
Islamabad, Pakistan
<affan.syed@nu.edu.pk>

Syed Ali Khayam
PLUMgrid Inc.
Sunnyvale, CA, USA
<khayam@plumgrid.com>

ABSTRACT
This paper aims to improve the accuracy of port-scan detectors by analyzing traffic of BitTorrent hosts and differentiating their respective BitTorrent connection (attempts) from port-scans. It is shown that by looking at BitTorrent coordination traffic and modeling port-scanning behavior the number of BitTorrent-related false positives can be reduced by 80% without any loss of IDS accuracy.

1. INTRODUCTION
1.1 Goal
Many internet attacks begin by scanning a number of addresses with the goal of finding an open port. This phenomenon is called “port-scanning”. Detecting a port-scan allows network administrators to identify an attack early enough to take protective measures for reducing or eliminating the ensuing damage. Detection methods for port-scans account for the fact that an attacker probes a large number of hosts in a considerably short span of time.

Another form of traffic which exhibits behavior similar to port-scans is peer-to-peer communication. In many P2P applications a host tries to initiate connections to a large number of peers. However, the presence of NATs and firewalls makes a significant number of these peers difficult or impossible to reach. This results in a number of failed handshake attempts which resemble port-scanning attempts. The absence of payload information in such connections also makes it impossible to use deep-packet inspection (DPI) for traffic labeling.

The false-positives triggered by P2P traffic in port-scan detectors makes it harder for security researchers and network administrators to profile network attacks. Similarly the inadequacy of DPI on failed handshakes reduces the effectiveness of network classification tools. To address these issues, this project inspects BitTorrent communication originating from a peer in order to predict its connection attempts to other peers. Consequently, those handshake failures which can be confidently labeled as P2P traffic are prevented from influencing results of port-scan detectors.

In addition to predicting the BitTorrent connections, this project models the behavior of port-scanners in order to find the port/peer ratio which can help differentiating between scan attempts and P2P traffic.

By using these features the goals of reducing port-scanning false-positives and enhancing traffic classification accuracy are achieved. The Bro IDS is used for developing and testing the traffic analyzer and the statistics for improvement are based upon its default scan detector.

1.2 Problem
1.2.1 Port-scanning
Many cyber attacks need to identify potential victims before exploiting their weaknesses. A popular method for discovering tractable hosts is port-scanning. It can be defined as probing several ports on a number of machines in order to find susceptible hosts. Some of the probes fail, some of them succeed but do not find any vulnerable service while some of them land at a port hosting a service which is further exploited by the attacker.

Detecting port scans provides network administrators the ability to take pre-emptive measures against an attack by identifying the attacker. Scan detectors look for N events of interest across a T-sized time window [9].

The first such algorithm in literature was that of Network Security Monitor (NSM) [5]. It flagged those hosts as malicious which contacted more than fifteen distinct destination IP addresses within a specified time-window.

The Snort IDS [12] uses two different pre-processors for scan detection. The first is packet-oriented. It detects malformed packets such as those used for stealth-scanning by nmap. The second method is connection-oriented and is similar to the NSM algorithm. It triggers alarm if a source IP address contacts X number of ports across Y number of IP addresses in Z seconds.

The Bro IDS [11] builds on the observation that scanners do not have extensive knowledge of the network topology and system configuration. Therefore, it uses failed connection attempts as indicators of port-scans. For traffic using one of the services specified in a configurable list, Bro populates its port-scan metrics only if the connection attempts fail. For all other traffic it keeps track of all connections regardless of their establishment. When the number of distinct destination addresses crosses a particular threshold N an alarm is triggered.

All of these methods face a number of difficulties in effec-
Figure 1: A typical port scan


tive port-scan detection. Temporal as well as spatial considerations impose limitations in the amount of connections that are tracked. With the explosive growth of Internet many legitimate user activities also resemble behavior similar to port-scans. For example, it is not uncommon for web users to initiate connections to dozens of different websites at once. While such usage is catered for by Bro’s strategy of tracking only failed connections, an issue remains in the case of P2P traffic.

P2P clients generally contact a large number of hosts in a short span of time and unlike other well-known services use arbitrary ports for their communication [6]. This makes their behavior not only similar to port-scans but also harder to classify than other well-known services without the help of deep-packet inspection. An example of the Bro scan detector raising false alarm is shown below:

```
$ bro -r bittorrent.pcap scan.bro
1317250200.756488 AddressScan 192.168.0.5 has scanned 20 hosts (32833/tcp)
1317250222.395888 ShutdownThresh shutdown threshold reached for 192.168.0.5
1317250222.425419 AddressScan 192.168.0.5 has scanned 101 hosts (45612/tcp)
1317250288.527706 ScanSummary 192.168.0.5 scanned a total of 326 hosts
1317250288.527706 PortScanSummary 192.168.0.5 scanned a total of 224 ports
```

1.2.2 P2P Handshake Failures

Network Address Translator (NAT) are devices that allow multiple hosts on a private network to communicate with the Internet using a single public IP. This is achieved by modifying network layer information on-the-fly. When an internal host initiates a connection to an outsider a dynamic mapping is created which allows the response to be forwarded to that particular host as shown in Figure 2. Unsolicited inbound connections are dropped since NAT simply does not know which internal host should receive the data. Figure 3 shows a NAT box receiving incoming data but does not know which internal client $A, D$ should the data be forwarded to.

Firewalls are devices which inspect traffic passing through them and filter it based on a set of rules. In basic implementations unsolicited inbound connections are rejected while outbound connections are allowed.

Hosts which are behind NAT and/or firewalls have restricted connectivity in terms of receiving inbound connections. In P2P terminology they are called unconnectable peers. The ratio of such peers is considerably high, ranging from 60% to 90% of all P2P users [2, 3].

When a P2P client needs to contact other peers it uses a number of methods to obtain a list of their addresses. The most primitive of these methods is to contact a central tracker and request peer lists. Other de-centralized methods such as distributed hash tables also exist for storing peer lists.

However, in popular protocols such as BitTorrent the peer lists returned to a client via these methods usually contains information about other peers regardless of their connectivity status. As a result, unconnectable peers are often present in these lists.

Unconnectable peers result in a large number of failed connection attempts which can negatively influence the false-positive rate of scan detectors such as Bro. The similarity of connectivity behavior of P2P hosts and a scanner is shown in Figure 4.

1.3 Solution

1.3.1 BitTorrent Communication Analysis

BitTorrent is the most popular P2P file-sharing protocol,
accounting for more than half of all P2P file sharing traffic \cite{10}. Files shared via BitTorrent are divided into equal-sized chunks. Peers download these pieces from each other while uploading them simultaneously to other peers as well. All the peers which are sharing a particular file at a time are collectively called a swarm.

Before peers start to download a file however, they need to coordinate first in order to locate each other. The BitTorrent coordination lines in Figure 5 take place before the actual traffic and hence can be used to predict the successful and failed connections originating from a peer.

The earliest method for BitTorrent coordination was via centralized trackers. Centralized trackers keep track of which peers are downloading a file. When a new peer wants to join the swarm it requests a peer list from the tracker. The tracker responds with a list of \( k \) randomly picked peers, containing both connectable and unconnectable hosts. Connection attempts to unconnectable hosts then subsequently results in failed TCP connections \cite{8}.

In order to alleviate the load on trackers as well as increase resilience against take-down attempts two de-centralized methods exist for obtaining peer lists: Distributed Hash Table (DHT) and Peer Exchange (PEX).

A DHT is a distributed database overlayed over a network of computers called nodes. All nodes can store (key, value) pairs on the DHT and search for values via key-lookups. In order to join a DHT a peer has to first contact a bootstrap node in that DHT. Currently, the BitTorrent community uses two major DHTs: the Azureus DHT and the Mainline DHT. The Azureus DHT is in use only by the Azureus clients while the Mainline DHT is used by other clients such as µTorrent, BitComent and Mainline. Both DHTs are implementations of the Kademlia protocol \cite{1}.

The second de-centralized method of peer discovery is PEX. In PEX peers “gossip” with each other in regular intervals about the list of active peers they know about \cite{13}. There is no official specification for the peer exchange protocol in BitTorrent. The de facto standard for Peer Exchange is µTorrent PEX.

All these methods of peer discovery can be interpreted by a traffic analyzer, with the exception of trackers that serve on HTTPS. By reading the peer lists returned via HTTP tracker, DHT or PEX it is possible to “predict” the BitTorrent connection attempts that are going to originate from a given source IP. This shall in turn make it possible to label failed connection attempts and differentiate them from port-scans.

2. IMPLEMENTATION

2.1 Bro IDS

The Bro IDS was used to develop and test the traffic analyze along with its scan detector for providing baseline statistics. During the course of development Bro’s core was modified to provide the following helper functions:

- **Listing 1**: `raw_ns_bytes_to_uint16`
  Interpret the first two bytes of a string as a 2-byte unsigned integer in network-byte order.
- **Listing 2**: `raw_nl_bytes_to_uint32`
  Interpret the first four bytes of a string as a 4-byte unsigned integer in network-byte order.
- **Listing 3**: `sub_bytes_sane`
  Bro’s default `sub_bytes` function had the idiosyncratic behavior in that it if the indices were greater than
2.2 Central Trackers

A central tracker keeps track of peers that are currently downloading a file and transfers this list to new peers that are trying to join the swarm.

There are two types of central tracker used by BitTorrent clients.

2.2.1 HTTP Tracker

A built-in analyzer was available in Bro for the HTTP tracker communication. However, using the peer lists extracted from this analyzer did not yield any connection hits. Therefore we manually analyzed the contents of TCP packets to extract peer lists whenever a specific regular expression is matched in the packet. This regular expression confirms the presence of peer list in the benc format that used by BitTorrent.

Any peers that are found in the peer lists are added to a global peer_mappings table which is indexed by source IPs and yields the (IP, Port) tuple for targets extracted from the peer list.

For example, if client \(X\) gets a peer list in which a peer \(A\) is listed as listening on port 6668, \((A, 6668)\) is added as a possible target for \(X\).

Listing 6 shows the code used by the HTTP analyzer to process each TCP packet.

2.2.2 UDP Tracker

The BitTorrent ecosystem is moving on to UDP trackers because of less overhead compared to HTTP trackers. Many major tracker websites such as The Pirate Bay and Mininova have already switched to UDP trackers. Bro did not have a built-in analyzer for the UDP tracker communication so we analyzed UDP traffic for packets of particular lengths and matched the action fields of the packet for announce_response. Once the UDP tracker communication was identified, announce_response helper function is called which in turn extracts the peer list and stores it in a global peer_mapping table.

Listing 7 shows the processing of each UDP packet by the UDP tracker analyzer.

2.3 Distributed Hash Tables

2.3.1 Azureus DHT

Table 3 and Table 4 show the packet structures for headers of ADHT packets. ADHT requests start with a random connection ID and do not have a fixed length. To identify these requests, the 16th byte of each UDP packet is checked for a valid ADHT protocol version. Based on the found protocol version, various offsets are added to a running counter corresponding to different fields.

Eventually, the originating port of the packet should appear in network-byte order at a specific offset. If that check does succeed, the packet is a valid ADHT request and bytes \([8, 12]\) are checked for ACTION field of the request.

Upon finding a valid ACTION, either a helper find_*_request function is called which in turn extract the TRANSACTION_ID and store it in a global table.

Similarly, all packets are checked for valid TRANSACTION_IDs from requests that have already been seen. If one is found, a helper find_*_response function is called which extracts the peer list out of the DHT values.
Listing 8 shows the code used by the ADHT analyzer to process each UDP packet.

### 2.3.2 Mainline DHT

For extracting Mainline DHT peer lists regular expressions are matched inside UDP packets for "nodes" and "values" responses. Upon matching the regular expressions the number of peers is determined and then each peer’s IP address and port number is extracted in a sequential manner. Listing 9 shows the code used by the MDHT analyzer to extract peers out of DHT responses.

### 2.3.3 Other DHTs

During the course of development we observed that certain UDP traffic flows between BitTorrent hosts before they initiate TCP connections. Matching this UDP traffic allows us to predict the TCP connections since the destination port remains same on both transport layer protocols. The signatures for matching miscellaneous DHT traffic were taken from libprotoident’s database, which is an open-source library for detecting application layer protocols from length of a payload combined with its first four bytes.

Listing 10 shows the code used by BTUDP analyzer to match signatures across each UDP packet. Once a BTUDP packet is detected, the target IP and port are added to safe peer_mappings.

### 2.4 Peer Exchange

Compatible BitTorrent clients “gossip” with each other about the clients they know exist in their swarm. This form of coordination is called Peer Exchange and is shown in Figure 8.

#### 2.4.1 UTPEX

µTorrent PEX or UTPEX is the de facto standard of Peer Exchange for BitTorrent clients. The packets are searched for regular expressions matching “added” responses which are sent by a client to its peers existing when it learns about new clients in the swarm. Listing 11 shows the code used by UTPEX analyzer for processing each TCP packet.

### 2.5 Port/Peer Ratio

Port/Peer Ratio is a feature which relies on behavioral differences between port scanners and BitTorrent downloaders. Before explaining these differences it is important to outline various categories in which a scanner’s behavior can be classified.

There are three kinds of port scans [7]. The first scan type is “horizontal” in which the attacker probes multiple hosts on the same port as shown in Figure 9. The motivation for such a scan stems from the fact that a known vulnerability would exist on that port.

The second scan type is “vertical” in which the attack probes a single host for multiple ports as shown in Figure 10. The motivation for such a scan lies in attacker targetting a specific victim to find any vulnerability he can find.

A hybrid or block scan is a combination of both horizontal and vertical scans and is shown in Figure 11.

In contrast, a P2P host contacts a large number of hosts on ports that are fairly random and almost unique since most of the hosts are behind NAT and have set up port-forwarding on non-standard ports. This is shown in Figure 12.

To use these observations, Port/Peer Ratio \( PPR \) of each host is kept track of. Ports correspond to unique ports while peers correspond to number of unique IP addresses that a hose has probed. From the discussion above:

- If \( PPR \) is close to 0, it indicates a horizontal scan.
- If \( PPR \) is close to 1, it indicates P2P behavior.
- If \( PPR \) is greater than 1, it indicates a vertical or hybrid scan.

Listing 12 shows code modifications to Bro’s scan detector for suppressing alarms when \( PPR \) of the attacker lies between a lower and upper threshold. By default these thresholds are specified as 0.75 and 1 respectively.

### 3. RESULTS
3.1 Controlled Experiment

For this experiment labeled data sets containing port scanners and BitTorrent hosts were used to gauge the IDS performance. With support of Dr. Ali Khayam we were able to obtain traces for 41 TCP port scanners which were generated at various rates for the RAID '10 paper [4] on impact of P2P on anomaly detection. In addition to the RAID data sets, nmap was used to generate traffic for 10 further scanners. The combined traces had 51 port scanners which scanned at rates varying from 0.01/s to 1000/s.

In order to process P2P traffic, BitTorrent traces were generated on 49 different virtual hosts. Various BitTorrent clients including Azureus, BitComet, Deluge, µTorrent, Transmission and FlashGet were used to generate the traffic on both Windows and Linux platforms. For each client application the default settings were used which resulted in unencrypted traffic for all hosts. It was ensured that the hosts were not infected at the time of traffic generation.

The traffic for both the scanners and BitTorrent hosts were aligned temporally to start at the same time while IP addresses were rewritten to avoid spatial collisions. The IP addresses were reassigned according to the criterion which assigned BitTorrent hosts and port scanners separate networks for ease of labeling.

To compare the performance of scan detector and its improvements ROC curves were used. The results are shown in Figure 13. Each point on the graph shows different thresholds for the number of addresses a host can probe within the 15 minute time window before being flagged as a scanner. At more relaxed thresholds, e.g., 1000, the points concentrated in the lower-left corner of the graph. Similarly, at stricter thresholds, e.g., 5, the points moved towards the upper-right corner of the graph as more scanners and BitTorrent hosts were flagged.

3.2 Live Traffic

For live traffic experiments a 400 GB trace was used which was captured at a Nayatel B-RAS over a duration of 24 hours.

We first ran BitTorrent Analyzer to figure out which connections could have been “predicted” by looking at the BitTorrent coordination traffic. Then we calculated the duration each BitTorrent host took to contact 100 predicted BitTorrent connections originated from A between 9:00 and 9:05 AM the duration would be 5 minutes. A histogram was generated with each bin denoting 15 minutes of time. As shown in Figure 14 most of the BitTorrent hosts generated 100 predicted BitTorrent connections in the first 15 minutes bin before being flagged as a scanner. The results indicate a strong influence of predicted BitTorrent connections on the scan flags.

Bro originally detected 202 scanners in the 400 GB trace. By filtering connections through the BitTorrent Analyzer the number of alarms was reduced to 32 as 170 flags were suppressed. We manually analyzed the remaining 32 hosts to observe that 26 of them were actual scanners while 6, or 3% of the original flags, were false alarms that were still being raised. These results are summarized in the pie-chart shown in Figure 15.

Conclusion

The original Bro scanner had a curve which bent significantly towards the lower-right corner of the graph. Adding the BitTorrent analyzer engine improved the performance of scan detector significantly without any loss of IDS accuracy since the curves do not intersect at any threshold. At the default Bro threshold, i.e., 100, the false positive rate is decreased from \( \frac{44}{49} = 89\% \) to \( \frac{1}{49} = 2\% \). By using the Port/Peer Ratio feature, the false positive rate is further improved to \( \frac{0}{49} = 0\% \).
Figure 14: Histogram depicting duration taken by BitTorrent hosts to initiate 100 predicted connections before being flagged as a scanner

Figure 15: Analysis of scan flags on the 400 GB live traffic trace

Conclusion

We concluded that almost all BitTorrent hosts generate false alarms because of their aggressive connectivity behavior. The BitTorrent Analyzer was able to reduce the number of false alarms significantly, however about 3% of the total flags still generated false positives.

4. References

[1] Crosby, S. A., and Wallach, D. S. An analysis of BitTorrent’s two Kademlia-based DHTs, 2007.

[2] D’Acunto, L., Meulpolder, M., Rahman, R., Pouwelse, J., and Sips, H. Modeling and analyzing the effects of firewalls and NATs in P2P swarming systems. In *IEEE IPDPS 2010 (HotP2P 2010)* (April 2010), pp. 1–8.

[3] D’Acunto, L., Pouwelse, J., and Sips, H. A measurement of NAT & firewall characteristics in peer-to-peer systems. In *Proc. 15-th ASCI Conference* (June 2009), Advanced School for Computing and Imaging (ASCI), pp. 1–5.

[4] Haq, I. U., Ali, S., Khan, H., and Khayam, S. A. What is the impact of P2P traffic on anomaly detection? In *Proceedings of the 13th international conference on Recent advances in intrusion detection* (Berlin, Heidelberg, 2010), RAID’10, Springer-Verlag, pp. 1–17.

[5] Heberlein, L. T., Dias, G. V., Levitt, K. N., Mukherjee, B., Wood, J., and Wolber, D. A network security monitor. *Security and Privacy, IEEE Symposium on* (1990), 296.

[6] Karagiannis, T., Broido, A., Brownlee, N., Claffy, K. C., and Faloutsos, M. Is P2P dying or just hiding? In *Proceedings of the GLOBECOM 2004 Conference* (Dallas, Texas, November 2004), IEEE Computer Society Press.

[7] Lee, C. B., Roedel, C., and Silenok, E. Detection and characterization of port scan attacks, 2003.

[8] Liu, Y., and Pan, J. The impact of NAT on BitTorrent-like P2P systems. In *Proceedings of 2009 9th IEEE International Conference on Peer-to-Peer Computing* (2009), pp. 242–251.

[9] Northcutt, S., and Novak, J. *Network Intrusion Detection: An Analyst’s Handbook*, 3rd ed. New Riders Publishing, Thousand Oaks, CA, USA, 2002.

[10] Opaque. Internet study 2008/09, 2009.

[11] Paxson, V. Bro: A system for detecting network intruders in real-time. *Computer Networks 31* (December 1999), 2435–2463.

[12] Roesch, M. Snort: Lightweight intrusion detection for networks. In *Proceedings of LISA ’99: 13th Systems Administration Conference* (1999), USENIX, pp. 229–238.

[13] Wu, D., Dhungel, P., Hei, X., Zhang, C., and Ross, K. W. Understanding peer exchange in BitTorrent systems. In *Proceedings of 2010 10th IEEE International Conference on Peer-to-Peer Computing* (2010), pp. 1–8.

APPENDIX

A. BRO MODIFICATIONS

```python
function raw_ns_bytes_to_uint16%(b: string%)
    count
        int32 u = 0;
        if ( b->Len() < 2 )
            builtin_error("too short a string as input to raw_bytes_to_uint16");
        else
            const uchar bp = b->Bytes();
            u = (bp[0] << 8) | bp[1];
        }
    return new Val(u, TYPE_COUNT);
%
```

Listing 1: raw_ns_bytes_to_uint16 helper function for Bro


**A.1 HTTP Tracker**

**A.2 UDP Tracker**

**A.3 Azureus DHT**

---

1 http://bittorrent.org/beps/bep_0015.html

2 http://wiki.vuze.com/w/Distributed_hash_table
Table 2: Serialization for ADHT values

| Name             | Width | Note                        |
|------------------|-------|-----------------------------|
| byte             | 1 byte| Single byte                 |
| short            | 2 bytes| Big endian                  |
| int              | 4 bytes| Big endian                  |
| long             | 8 bytes| Big endian                  |
| boolean          | 1 byte| False = 0. True = 1         |
| address          | 16 bytes| First byte indicates length of the IP address (4 for IPv4, 16 for IPv6); next comes the address in network byte order; the last value is port number as short |
| contact          | 16 bytes| First byte indicates contact type, which must be UDP (1); second byte indicates the contact's protocol version; the rest is an address |

Table 3: Header for ADHT requests

| Name             | Type | Protocol Version | Note                        |
|------------------|------|------------------|-----------------------------|
| CONNECTION_ID     | int  | always           | Random number with most significant bit set to 1 |
| ACTION           | int  | always           | Type of the packet          |
| REQUEST_ID       | int  | always           | Unique number used through the communication, it is randomly generated at the start of the application and increased by 1 with each sent packet |
| VERSION_ID       | byte | always           | Version of protocol used in this packet |
| VERSION          | byte | VERSION_ID       | 16 of the DHT implementation; 0 = Amor, 1 = ShareNet, 255 = unknown |
| LOCAL_PROTOCOL_VERSION | int | 256              | 16 of the network; if static version; 0 = UDP version |
| NODE_ADDRESS     | addr | always           | Address of the local node    |
| TRANSACTION_ID   | int  | always           | Application unique number, randomly generated at the start |
| TIME             | long | always           | Time of the local node, stored as number of milliseconds since Epoch |

Listing 9: mdht_find_values helper function for MDHT analyzer

A.5 Other DHTs

A.4 Mainline DHT

function parse_values(u: connection, is_orig: bool, contents: string) { ...

Listing 8: udp_contents event handler for ADHT analyzer

Listing 7: mdht_find_values helper function for MDHT analyzer
| Name               | Type   | Protocol Version | Note                  |
|--------------------|--------|------------------|-----------------------|
| TRANSACTION_ID     | int    | always           | Must be equal to TRANSACTION_ID from the request |
| TRANSACTION_TYPE   | long   | always           | Must be equal to TRANSACTION_TYPE from the request |
| PORT               | int    | always           | Version of protocol used in this packet |
| VENDOR_ID          | byte   | ≥                | Same meaning as in the request |
| NETWORK_ID         | int    | ≥ NETWORK_ID     | Same meaning as in the request |
| INSTANCE_ID        | int    | always           | Instance id of the node that replies to the request |

**Table 4: Header for ADHT replies**

26 if (is_orig) {
27     orig = u$id$orig$h;
28     peer$h = port_to_count(u$id$resp$h);
29     peer$p = port_to_count(u$id$orig$h);
30 } else {
31     orig = u$id$resp$h;
32     peer$h = port_to_count(u$id$orig$h);
33     peer$p = port_to_count(u$id$resp$h);
34 }
35 if (orig !in peer$mappings) {
36     peer$mappings[orig] = set();
37     add peer$mappings[orig][peer];
38 }
39

**Listing 10: udp_contents helper function for BTUDP analyzer**

**A.6 UTPEX**

**Listing 11: tcp_contents event handler for UTPEX analyzer**

**A.7 Port/Peer Ratio**

**Listing 12: check_scan alarm suppression for PPR**