# TOS Covert Channel: Implementation, Performance Analysis, and Experimental Results

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**Abstract**

This report presents the design, implementation, and performance evaluation of a covert channel that exploits the IP Type of Service (TOS) field. The channel uses a header/payload structure with control packets for session delimitation and redundancy for robustness. Experiments were conducted by varying TOS Mapping Bits, redundancy (packets-per-symbol), and sender interval parameters via terminal commands. Combined measurement results from both the sender and receiver sides are summarized in tables and further illustrated with graphical analyses. Additionally, statistical analysis including a 95% confidence interval is computed for key metrics.

# 1 Introduction

Covert channels enable secret communication by bypassing standard network protocols. In this implementation, the IP TOS field is manipulated to encode covert data. The sender and receiver are fully parameterized to allow experiments with various configurations:

- **TOS Mapping Bits:** The number of bits used from the TOS field (1, 2, 4, or 8).
- **Redundancy (Packets per Symbol):** The number of redundant packets for each symbol (e.g., 1, 2, or 3).
- **Sender Interval:** The inter-packet delay (0.01 s and 0.1 s).

Terminal commands were executed to vary these parameters during testing.

# 2 Implementation Details

## 2.1 Sender Implementation

The sender performs the following steps:

1. **Message Encoding:** The message is converted to its 8-bit ASCII binary representation and segmented into symbols based on the specified TOS Mapping Bits; padding is added if necessary.
2. **Header Construction:** A header is constructed to encode the number of payload symbols using at least 16 bits (rounded up to a multiple of the TOS Mapping Bits).
3. **Packet Transmission:** Control packets (`START` and `END`) are sent to mark session boundaries. Data packets (with TOS values corresponding to each symbol) are transmitted with configurable redundancy.
4. **Interval Control:** A user-defined interval is maintained between packet transmissions.

### 2.2 Receiver Implementation

The receiver:

1. **Packet Filtering:** Listens on a specified UDP port and filters packets with the expected payload and TOS field.
2. **Session Demarcation:** Uses control packets to switch modes. A `START` packet triggers header collection (which determines the number of payload symbols), while an `END` packet signals the end of the session.
3. **Redundancy Resolution:** Applies majority voting on redundant packets to determine the correct symbol for each position.
4. **Performance Measurement:** Computes the message transmission time and channel capacity, where capacity is calculated as the total number of payload bits divided by the elapsed time.

### 2.3 Test Methodology

Experiments were conducted by varying terminal command parameters. For instance, the following commands were used for TOS Mapping Bits = 8, redundancy = 3, and sender interval = 0.1 s:

```
python3 tos_covert_sender.py --message "Test Covert Channel" \
  --tos-mapping-bits 8 --interval 0.1 --packets-per-symbol 3 \
  --repeat-message 1 --target-ip 10.0.0.15 --port 8888

python3 tos_covert_receiver.py --tos-mapping-bits 8 \
  --packets-per-symbol 3 --timeout 180 --iface eth0
```

Similar commands were executed to vary TOS Mapping Bits, redundancy, and sender interval.

## 3 Experimental Results

Combined results for sender and receiver are grouped by TOS Mapping Bits value. The following tables summarize the performance metrics with 95% confidence intervals.

## 3.1 TOS Mapping Bits = 1

Table 1: Combined Results for TOS Mapping Bits = 1 with 95% Confidence Intervals

| Redundancy | Sender Interval (s) | Sender Time (s) | Symbols | Total Pkts | Receiver Time (s) | Capacity (bit/s) |
|---|---|---|---|---|---|---|
| 1 | 0.01 | 8.748 [7.891 - 9.605] | 152 | 174 | 8.540 [7.703 - 9.377] | 17.798 [16.054 - 19.542] |
| 1 | 0.1 | 24.007 [21.654 - 26.360] | 152 | 174 | 23.441 [21.144 - 25.738] | 6.484 [5.849 - 7.119] |
| 2 | 0.01 | 16.997 [15.331 - 18.663] | 152 | 342 | 16.757 [15.115 - 18.399] | 9.071 [8.182 - 9.960] |
| 2 | 0.1 | 46.740 [42.159 - 51.321] | 152 | 342 | 46.159 [41.635 - 50.4883] | 3.293 [2.970 - 3.616] |
| 3 | 0.01 | 24.547 [22.141 - 26.953] | 152 | 510 | 24.353 [21.966 - 26.740] | 6.241 [5.629 - 6.853] |
| 3 | 0.1 | 69.489 [62.679 - 76.299] | 152 | 510 | 68.923 [62.169 - 75.677] | 2.205 [1.989 - 2.421] |

## 3.2 TOS Mapping Bits = 2

Table 2: Combined Results for TOS Mapping Bits = 2 with 95% Confidence Intervals

| Redundancy | Sender Interval (s) | Sender Time (s) | Symbols | Total Pkts | Receiver Time (s) | Capacity (bit/s) |
|---|---|---|---|---|---|---|
| 1 | 0.01 | 5.073 [4.576 - 5.570] | 76 | 90 | 4.830 [4.357 - 5.303] | 31.472 [28.388 - 34.556] |
| 1 | 0.1 | 12.657 [11.417 - 13.897] | 76 | 90 | 12.032 [10.853 - 13.211] | 12.633 [11.395 - 13.871] |
| 2 | 0.01 | 9.196 [8.295 - 10.097] | 76 | 174 | 8.891 [8.020 - 9.762] | 17.096 [15.421 - 18.771] |
| 2 | 0.1 | 23.624 [21.309 - 25.939] | 76 | 174 | 23.048 [20.789 - 25.307] | 6.595 [5.949 - 7.241] |
| 3 | 0.01 | 12.384 [11.170 - 13.598] | 76 | 258 | 12.182 [10.988 - 13.376] | 12.478 [11.255 - 13.701] |
| 3 | 0.1 | 35.492 [32.014 - 38.970] | 76 | 258 | 34.912 [31.491 - 38.333] | 4.354 [3.927 - 4.781] |

## 3.3 TOS Mapping Bits = 4

Table 3: Combined Results for TOS Mapping Bits = 4 with 95% Confidence Intervals

| Redundancy | Sender Interval (s) | Sender Time (s) | Symbols | Total Pkts | Receiver Time (s) | Capacity (bit/s) |
|---|---|---|---|---|---|---|
| 1 | 0.01 | 2.417 [2.180 - 2.654] | 38 | 48 | 2.217 [2.000 - 2.434] | 68.569 [61.849 - 75.289] |
| 1 | 0.1 | 6.589 [5.943 - 7.235] | 38 | 48 | 5.968 [5.383 - 6.553] | 25.469 [22.973 - 27.965] |
| 2 | 0.01 | 4.272 [3.853 - 4.691] | 38 | 90 | 4.014 [3.621 - 4.407] | 37.865 [34.154 - 41.576] |
| 2 | 0.1 | 12.351 [11.141 - 13.561] | 38 | 90 | 11.773 [10.4819 - 12.927] | 12.910 [11.645 - 14.175] |
| 3 | 0.01 | 6.548 [5.906 - 7.190] | 38 | 132 | 6.278 [5.663 - 6.893] | 24.210 [21.837 - 26.583] |
| 3 | 0.1 | 18.143 [16.365 - 19.921] | 38 | 132 | 17.574 [15.852 - 19.296] | 8.649 [7.801 - 9.497] |

## 3.4 TOS Mapping Bits = 8

Table 4: Combined Results for TOS Mapping Bits = 8 with 95% Confidence Intervals

| Redundancy | Sender Interval (s) | Sender Time (s) | Symbols | Total Pkts | Receiver Time (s) | Capacity (bit/s) |
|---|---|---|---|---|---|---|
| 1 | 0.01 | 1.363 [1.229 - 1.497] | 19 | 27 | 1.149 [1.036 - 1.262] | 132.274 [119.311 - 145.237] |
| 1 | 0.1 | 3.747 [3.380 - 4.114] | 19 | 27 | 3.132 [2.825 - 3.439] | 48.530 [43.774 - 53.286] |
| 2 | 0.01 | 2.496 [2.251 - 2.741] | 19 | 48 | 2.301 [2.076 - 2.526] | 66.062 [59.588 - 72.536] |
| 2 | 0.1 | 6.548 [5.906 - 7.190] | 19 | 48 | 5.962 [5.378 - 6.546] | 25.493 [22.995 - 27.991] |
| 3 | 0.01 | 3.376 [3.045 - 3.707] | 19 | 69 | 3.201 [2.887 - 3.515] | 47.488 [42.834 - 52.142] |
| 3 | 0.1 | 9.665 [8.718 - 10.4812] | 19 | 69 | 9.077 [8.187 - 9.967] | 16.746 [15.105 - 18.387] |

# 4 Graphical Analysis

The following figures were generated during the experiments and illustrate the observed trends:

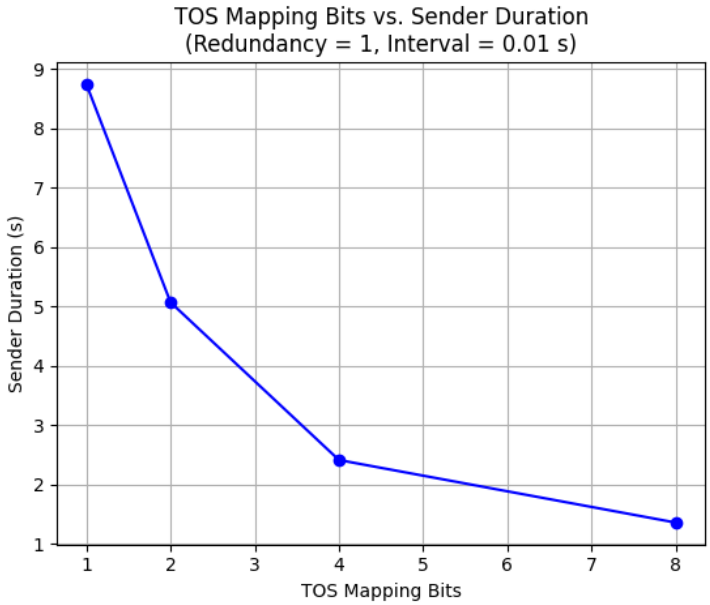


Figure 1: Plot 1: Effect of varying TOS Mapping Bits on Sender Duration. The plot (with redundancy fixed at 1 and sender interval set to 0.01 s) shows that as TOS Mapping Bits increase, the sender duration decreases.

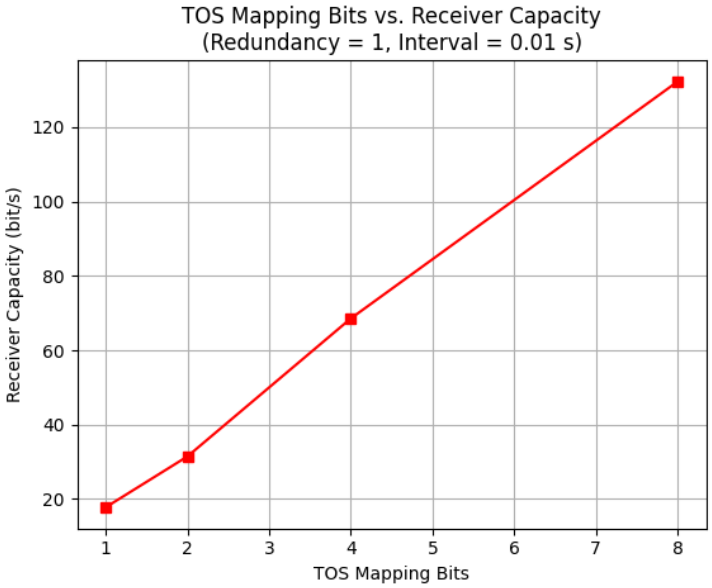


Figure 2: Plot 2: Effect of varying TOS Mapping Bits on Receiver Capacity. With redundancy = 1 and sender interval = 0.01 s, receiver capacity improves as TOS Mapping Bits increase.

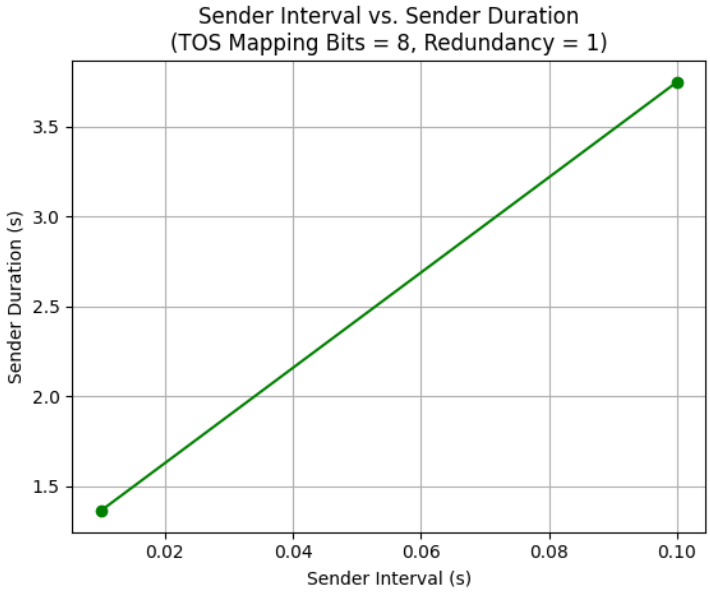


Figure 3: Plot 3: Sender Interval vs. Sender Duration for TOS Mapping Bits = 8 (Redundancy fixed at 1). This plot illustrates how the sender duration changes when the sender interval is varied, for the case where TOS Mapping Bits is 8.

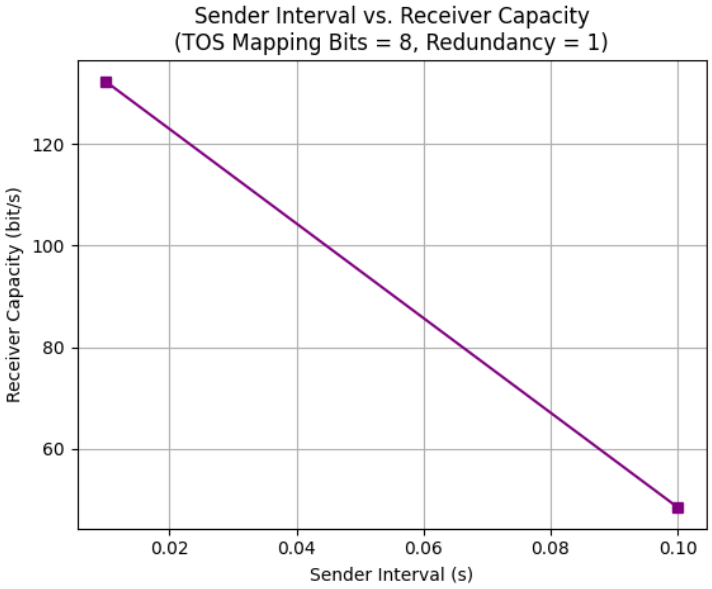


Figure 4: Plot 4: Sender Interval vs. Receiver Capacity for TOS Mapping Bits = 8 (Redundancy fixed at 1). This plot demonstrates the variation in receiver capacity as the sender interval changes, with TOS Mapping Bits fixed at 8.

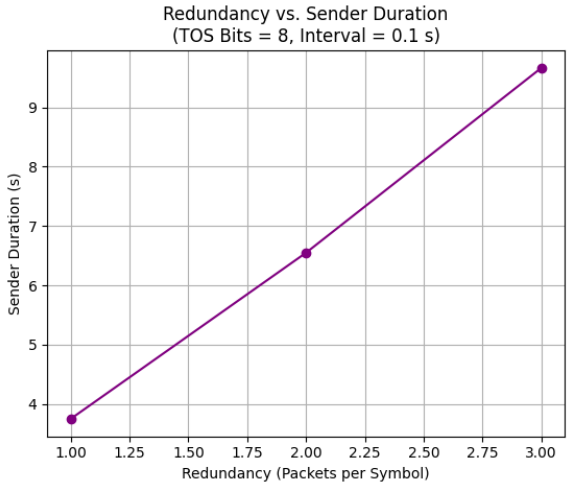


Figure 5: Plot 5: Effect of Redundancy on Sender Duration for TOS Mapping Bits = 8 at a fixed sender interval of 0.1 s. Higher redundancy increases the sender duration.

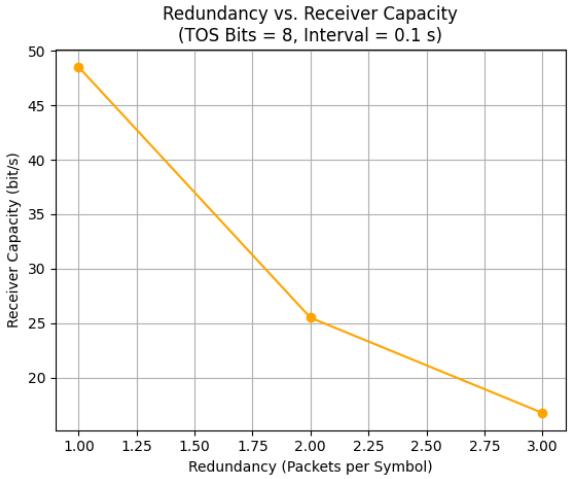


Figure 6: Plot 6: Effect of Redundancy on Receiver Capacity for TOS Mapping Bits = 8 at a fixed sender interval of 0.1 s. As redundancy increases, the receiver capacity decreases.

# 5 Discussion

The experimental results reveal several important trends:

- **Effect of TOS Mapping Bits:** Increasing the number of TOS Mapping Bits reduces the number of payload symbols required, leading to shorter sender durations and higher receiver capacity.
- **Impact of Redundancy:** Higher redundancy improves reliability via majority voting but increases transmission time and reduces effective channel capacity.
- **Sender Interval Influence:** Shorter sender intervals reduce the total transmission time and increase receiver capacity; however, very aggressive intervals might impact reliability under congested conditions.