First Person Shooter Games (FPS)
Two Player Packet Length Distributions

Tony Cricenti

Outline

- Background of FPS Traffic
- Standard Distributions
- Distribution Fits for 2 Player Games
- Where to from here?
- Conclusions
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Background: FPS Games Traffic

- Considerable amount of work in describing the statistical distribution of the traffic parameters of FPS games.
  - E.g.: Borella for Quake I and Quake II, Lakkakorpi et. al for Quake II, Lang et. al Halo I, Half-Life and Quake III, Farber for Half-Life Counter-Strike, Zander et al. for Halo 2, etc.
  - FPS traffic model has been proposed for IEEE 802.16m Evaluation Methodology Document (EMD) (80216m).
Background: FPS Games Traffic

Packet inter-arrival times:

- Server to client direction:
  - discrete or degenerate distributions
- Client to server direction:
  - generally depend on the platform’s hardware
  - typically modelled by a combination of different distributions.
    - Extreme Value and Exponential distributions Quake I and Quake II
    - Extreme Value and Gaussian distribution Quake II
    - Degenerate and Exponential distributions for Quake III

Not very interesting…

Packet Payloads - Client to Server (C2S):

- Typically the payload size varies over a small range
  - Gaussian distributions with small variances
    - Half-Life, Quake III
  - Extreme Value distributions
    - Half-Life Counter-Strike
  - FPS game model for IEEE 802.16m (80216m)
  - Fixed size Quake, Quake II
- Client to server packet payload size is independent of the number of clients in the game
  - Halo and Halo II games the payload size varies with the number of players active on a particular client
Background: FPS Games Traffic

- Packet Payloads - Server to Client (S2C):
  - Exhibit substantial variations in payload size
  - Strongly dependent on the number of players in the game
  - Distribution is typically skewed. Commonly modelled by either
    - Extreme Value distributions
      - Quake and Quake II,
      - Half-Life Counter-Strike
      - Halo II
      - FPS game model for IEEE 802.16m (80216m)
    - Log-normal distributions Half-Life, Quake III Arena

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Standard Distributions

- Common statistical distributions used for FPS models:
  - Gaussian (normal) – symmetrical. Properties well known
  - Log-normal – skewed. Properties well known
  - Extreme Value - skewed.

Background: FPS Games Traffic

- The Extreme Value and Log-normal distributions have been chosen to fit the observed data as they are able to capture the skewness in the distribution of the empirical data.

- To-date there have been limited attempts at describing why the underlying process leads to payload sizes that are either Extreme, Log-normal or Gaussian distributed.
Extreme Distribution

- Many authors fit an Extreme Value distribution to FPS traffic parameters

  - What process gives rise to this distribution?
  - Consider the largest value drawn from $N$ independent exponentially distributed random variables:

Ex-gauss Distribution

- The Ex-gauss distribution is a skewed mixture distribution that has been used to model reaction times.

- Arises from the sum of two random variables, one of which is Gaussian distributed ($\mu, \sigma$) and the other exponentially distributed ($\lambda$).

- pdf

\[ f(x; \mu, \sigma, \lambda) = \frac{\lambda}{\sigma} \exp\left(\mu \lambda + \frac{\sigma^2 \lambda^2}{2} - \lambda x\right) \phi\left(\frac{x - \mu - \lambda \sigma^2}{\sigma}\right) \]

Where $\Phi(\cdot)$ is the unit Gaussian Distribution.
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Two Player Game

Non-deterministic!
Methodology

- Traffic traces for 7 FPS games form the SONG database:
  - Half-Life,
  - Half-Life Counter-Strike,
  - Quake III Arena,
  - Quake IV,
  - Wolfenstein Enemy Territory Pro,
  - Half-Life 2
  - and Counter-Strike: Source

The traffic traces were collected from games that were run under controlled conditions


Traces were truncated both at the beginning and end to ensure that only the traffic during the game-play phase was retained.

The packet lengths discussed are the UDP payload size of the IP datagrams.
Methodology

- Fit Normal, Log-normal, Generalised Extreme Value (GEV) and Ex-gauss distributions to payloads for 2 player games.
- Extreme Value Distribution special case of GEV.
- Maximum likelihood estimation (MLE) approach and the MATLAB Statistics Toolbox.
- Some traces where censored to remove any outliers and periodic components. The details of the censoring of the data are given when this has occurred.

Methodology

- Distribution of best fit determined by:
  - inspecting the CDFs (QQ plots if necessary)
  - the size of $\lambda^2$ discrepancy measure
- Typical approach used in the literature when fitting distributions to FPS game empirical data-sets.
### Results: Client to Server Payload Size

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Min (B)</th>
<th>Max (B)</th>
<th>Mean</th>
<th>Variance</th>
<th>(\lambda^2) Discrepancy Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exp(Gauss)</td>
<td>GEV</td>
<td>LogNorm</td>
<td>Gauss</td>
<td></td>
</tr>
<tr>
<td>Q3</td>
<td>25</td>
<td>45</td>
<td>32.9</td>
<td>10.6</td>
<td>0.439 0.443 0.981 0.439</td>
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<tr>
<td>ETPro</td>
<td>27</td>
<td>45</td>
<td>32.3</td>
<td>7.4</td>
<td>0.667 0.400 0.556 0.826</td>
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<td>HL2Dm</td>
<td>10</td>
<td>102</td>
<td>55.9</td>
<td>117.5</td>
<td>2.132 1.740 1.740 2.326</td>
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<td>HL2Cs</td>
<td>33</td>
<td>90</td>
<td>51.2</td>
<td>100.1</td>
<td>3.743 4.268 4.892 3.733</td>
</tr>
<tr>
<td>HLDM</td>
<td>31</td>
<td>72</td>
<td>47.1</td>
<td>39.3</td>
<td>0.135 0.080 0.123 0.138</td>
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<tr>
<td>HLCS</td>
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<td>97</td>
<td>43.2</td>
<td>49.8</td>
<td>0.392 0.398 0.407 0.428</td>
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<tr>
<td>Q4</td>
<td>42</td>
<td>52</td>
<td>48.2</td>
<td>2.8</td>
<td>0.031 0.035 0.030 0.036</td>
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<tr>
<td></td>
<td>53</td>
<td>83</td>
<td>61.3</td>
<td>16.7</td>
<td>0.113 0.373 0.187 0.113</td>
</tr>
</tbody>
</table>

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### Results: C2S Quake III Arena

- Little difference in the fit for the four distributions, however, the Ex-gauss, GEV and Gaussian distributions have the lowest \(\lambda^2\) discrepancy measure.
- Lang et al. Gaussian is the best fit distribution.
Results: C2S Wolfenstein Enemy Territory Pro

- GEV distribution provides the best fit and has the lowest $\chi^2$ discrepancy.
- Censored the trace to remove periodic 47 byte packet (relative frequency 0.153%)

QQ plots: Ex-gauss and GEV distributions better fit to lower tail, whilst the Log-normal provides a better fit to the upper tail (>40 bytes).
Results: C2S Half-Life 2

- Best fit distribution lowest $\lambda^2$ discrepancy: GEV and Log-normal.
  - The censored trace: a number of small packets (10 bytes) removed.
- Log-normal does not fit the upper tail well.

Results: C2S Counter-Strike: Source

- Ex-Gauss and Gaussian distributions result in the best fit. Lowest $\lambda^2$ discrepancy
Results: C2S Half-Life

- Not much difference in the fit of the various distributions. GEV distribution has the lowest $\lambda^2$ discrepancy.

Results: C2S Half-Life Counter-Strike

- $\lambda^2$ discrepancy is similar for all four distributions
- GEV and Ex-gauss distributions fit the lower tail better
- Gaussian and Log-normal fit the upper tail better.
Results: C2S Quake IV

- Traced censored to remove periodic packets (25 bytes).
- Distribution is bi-modal: separate into 2 parts.
- Upper distribution, GEV highest $\lambda^2$ discrepancy (worst fit)
- Lower distribution there is no clear best fit distribution, all four distributions having similar $\lambda^2$ discrepancy

Results: Discussion

- No clear winner for the C2S packet payload size.
- Generally there is little difference in the $\lambda^2$ discrepancy measure for the four distributions studied.
- May be due to small variation in the range of packet payload sizes.
- Data is discrete with small support, fitting discrete distributions may lead to better demarcation.
  - This possibility needs to be explored further.
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<th>GEV</th>
<th>LogNorm</th>
<th>Gauss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q3</td>
<td>19</td>
<td>275</td>
<td>60.5</td>
<td>328.8</td>
<td>0.099</td>
<td>0.141</td>
<td>0.160</td>
<td>0.638</td>
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<tr>
<td>ETPro</td>
<td>21</td>
<td>495</td>
<td>71.7</td>
<td>793.2</td>
<td>0.081</td>
<td>0.083</td>
<td>0.119</td>
<td>0.082</td>
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<tr>
<td>HL2DM</td>
<td>39</td>
<td>400</td>
<td>94.8</td>
<td>1510.2</td>
<td>0.159</td>
<td>0.166</td>
<td>0.302</td>
<td>0.958</td>
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<tr>
<td>HL2CS</td>
<td>33</td>
<td>248</td>
<td>66.5</td>
<td>592.8</td>
<td>0.363</td>
<td>0.474</td>
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<td>0.732</td>
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<tr>
<td>HLDM</td>
<td>27</td>
<td>250</td>
<td>63.9</td>
<td>581.7</td>
<td>0.070</td>
<td>0.071</td>
<td>0.374</td>
<td>1.235</td>
</tr>
<tr>
<td>HLCS</td>
<td>27</td>
<td>501</td>
<td>53.4</td>
<td>595.8</td>
<td>1.570</td>
<td>1.639</td>
<td>3.241</td>
<td>3.301</td>
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<tr>
<td>Q4</td>
<td>35</td>
<td>250</td>
<td>89.9</td>
<td>924</td>
<td>0.797</td>
<td>0.927</td>
<td>1.231</td>
<td>0.740</td>
</tr>
</tbody>
</table>

### Results: S2C Quake III Arena

- Ex-gauss best fit based on $\lambda^2$ discrepancy metric
Results: S2C Wolfenstein Enemy Territory Pro

- Strong periodic component. (~21 bytes) removed from trace (approximately 3% of the packets).
- Ex-gauss, Gaussian the GEV have lowest $\lambda^2$ discrepancy
- QQ plots reveal that the GEV and the Ex-gauss fit both tails better.

Results: S2C Half-Life 2

- For the censored trace, packets of size greater than 400 bytes were removed. (~ 1.6% of the total packets).
- Ex-gauss and GEV distributions provide the best fit
Results: S2C Counter-Strike: Source

- Censored data, keep packets whose size in range of 33 to 248 bytes (~92% of the packets)
  - Ensure that the large peaks in pdf did not bias the fit.
- Ex-gauss and GEV best fit (lowest $\lambda^2$).

Results: S2C Half-Life

- Censored trace: packets > 250 bytes were removed
- Ex-gauss and GEV distributions best fit (lowest $\lambda^2$).
Results: S2C Half-Life Counter-Strike

- Censored trace, keep only packets of size ranging from 35 to 250 bytes.
- Ex-Gauss and GEV best fit (lowest $\lambda^2$).

Results: S2C Quake IV

- Censored trace: periodic packets < 30 bytes removed.
- Density is multimodal
  - difficult to clearly identify a single best fit distribution.
  - Gaussian and Ex-Gauss distributions have the (lowest $\lambda^2$)
Discussion

- GEV and Ex-gauss both good candidates for S2C payload
  - Unlike Gaussian and Log-normal, shape of the GEV and Ex-gauss can be adjusted so they provide a good fit.
  - Can adjust location, scale and shape parameters independently
  - Ex-gauss tends to Gaussian small $\lambda$

- Why is the extreme distribution popular in the literature to describe the packet payload statistics of FPS games?
  - Have shown that another distribution can be used to achieve the same end.

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- From empirical results: Ex-gauss is a good candidate to model the S2C packet payload.
- How is C2S packet distributed? (Gaussian?)
- Is the Server packet constructed as shown?

From empirical results: Ex-gauss is a good candidate to model the S2C packet payload.

How is C2S packet distributed? (Gaussian?)

Is the Server packet constructed as shown?

Ex-gauss

Fixed Part
Client 1 Contribution
Client 2 Contribution
Server Contribution

Gaussian? Exponential?

Look at code!!!

Where to from here?

- Branch et al. showed that the density of S2C payload size for a N (even) player game is related to the N fold convolutions of 2-player game densities.

- E.g. Four player game:

\[ f_4(x) = f_2(x) \times f_2(x) \]

- If payload is Ex-gauss distributed then:

\[ f_4(x) = f_{ex-gauss}(x) \times f_{ex-gauss}(x) \]

\[ f_4(x) = f_{normal}(x) \times f_{exponential}(x) \times f_{normal}(x) \times f_{exponential}(x) \]

\[ f_4(x) = f_{normal}(x) \times f_{gamma}(x) \]

- may be able to avoid the convolution…
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Conclusion

- Fitted four distributions (Gaussian, Log-normal, Generalised Extreme Value and the Ex-gauss) to the packet payload sizes for two-player games of seven popular FPS games.
- Client to server direction:
  - Difficult to clearly choose a winner between the four distributions for payload size
  - In several cases there is little difference in the $\lambda^2$ metric for the fit of the four distributions.
Conclusion

- Server to Client direction:
  - Ex-gauss and Generalised Extreme Value distributions result in best fits (except Quake IV)
  - Both these distributions are versatile as their shape can be adjusted independently to fit the data’s density.
  - Based on empirical data the Ex-gauss is a suitable distribution.
  - Need to better understand the underlying process of the FPS game to firm up this conclusion.

Questions

- Thank you