The background of the slide is a composite image. It features a night-time aerial view of a city, likely New York City, with numerous skyscrapers and buildings illuminated with lights. Overlaid on this cityscape is a network diagram. The diagram consists of various blue icons connected by lines. The icons include a brain with a gear, a cloud, a shopping cart, a Wi-Fi symbol, a house, a factory, a person, a laptop, a bar chart, and a hexagon with a building. The lines connecting these icons are a mix of solid and dashed blue lines, creating a web-like structure across the top and middle of the image. In the top left corner, there is a solid orange horizontal bar.

System Performance Evaluation 2

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A Bit More Theory

Recap: confidence intervals

- Is the mean estimate good enough?
- A good way of answering is
 - choosing a **significance level** α ,
 - finding the interval (a,b) (**confidence interval** for α) such that:

$$P(a \leq \mu \leq b) = 1 - \alpha$$

- A and b are computed with the Central Limit Theorem

Recap: confidence intervals

- Thus, the confidence intervals for μ can be obtained assuming the mean distribution is gaussian:

$$a = \bar{x} - Z_{(1-\alpha)/2} \cdot \frac{s}{\sqrt{n}}$$

$$b = \bar{x} + Z_{(1-\alpha)/2} \cdot \frac{s}{\sqrt{n}}$$

- Where $Z_{(1-\alpha)/2}$ is the $(1-\alpha)/2$ -quantile of half $N(0,1)$. It is derived from tables.
- Remember s is the standard deviation.

How Long Should Our Simulation Be?

- Or, how large should n be for the mean to be in a smaller enough interval with a larger enough confidence?

- Suppose we want:

$$P(\bar{x} - r\bar{x} \leq \bar{x} \leq \bar{x} + r\bar{x}) = 1 - \alpha$$

- This means:

$$\bar{x} - r\bar{x} = a = \bar{x} - Z_{(1-\alpha)/2} \cdot \frac{s}{\sqrt{n}}$$

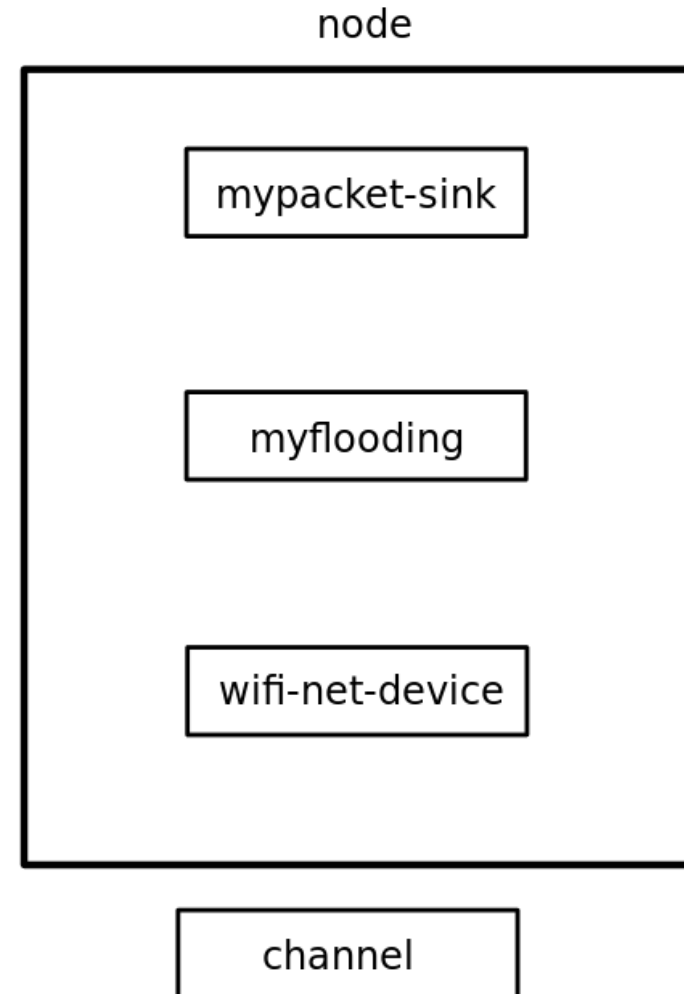
- And thus:

$$n = \left(\frac{Z_{(1-\alpha)/2} \cdot s}{r\bar{x}} \right)^2$$

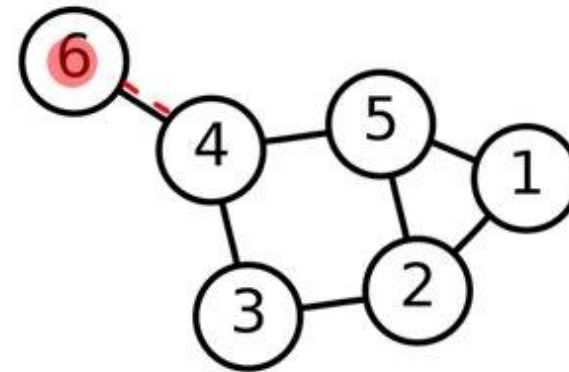
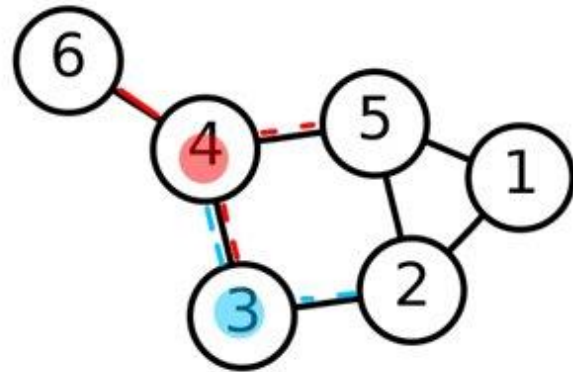
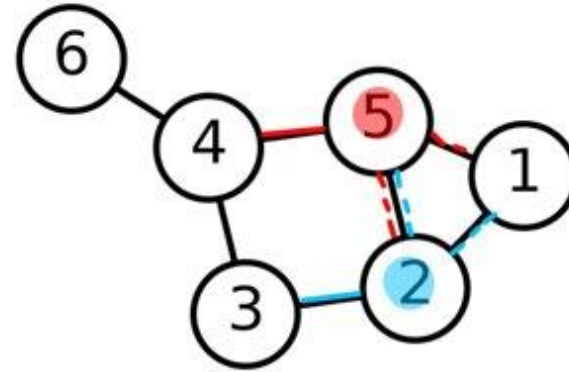
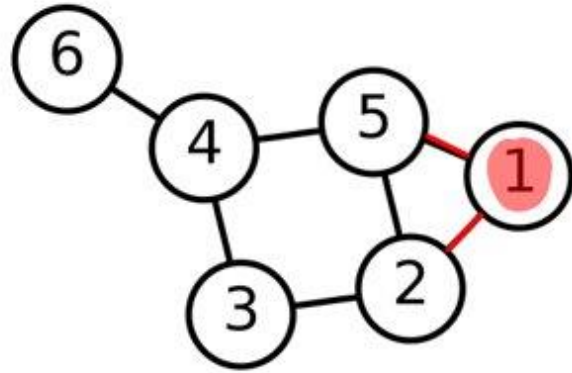
Ns-3 Simulation Code Example

Code Structure

- Application (new module): All nodes send to a sink.
- Routing (new module): Flooding.
- MAC and Phy: Wi-fi ad-hoc (IEEE 802.11ah).
- We want to compute the packet latency of this system.



Flooding: Brief Recap



Create New Module

- `cd <your-ns3-folder>`
- Create new module in contrib names mymodule:

```
./utils/create-module.py  
    contrib/mymodule
```

- Configure examples building:
`./waf configure --enable-examples`

- Build:

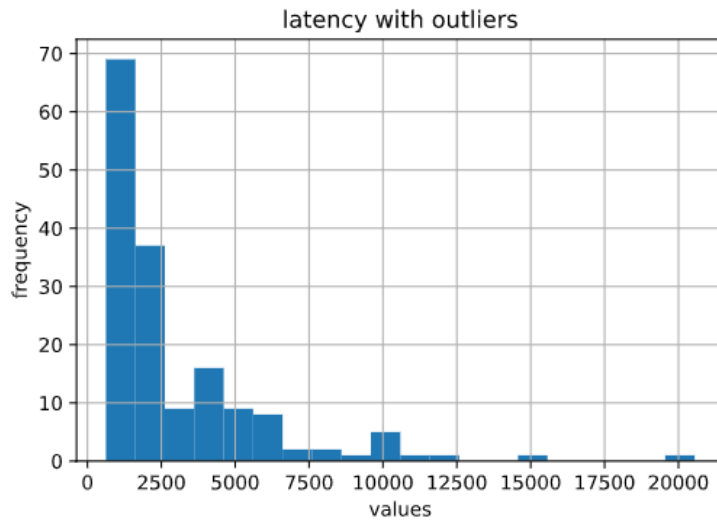
```
./waf
```

✓ contrib	●
✓ mymodule	●
✓ doc	●
≡ mymodule.rst	U
✓ examples	●
⚙ mymodule-example.cc	U
≡ wscript	U
✓ helper	●
⚙ mymodule-helper.cc	U
📄 mymodule-helper.h	U
✓ model	●
⚙ mymodule.cc	U
📄 mymodule.h	U
✓ test	●
⚙ mymodule-test-suite.cc	U
≡ wscript	U

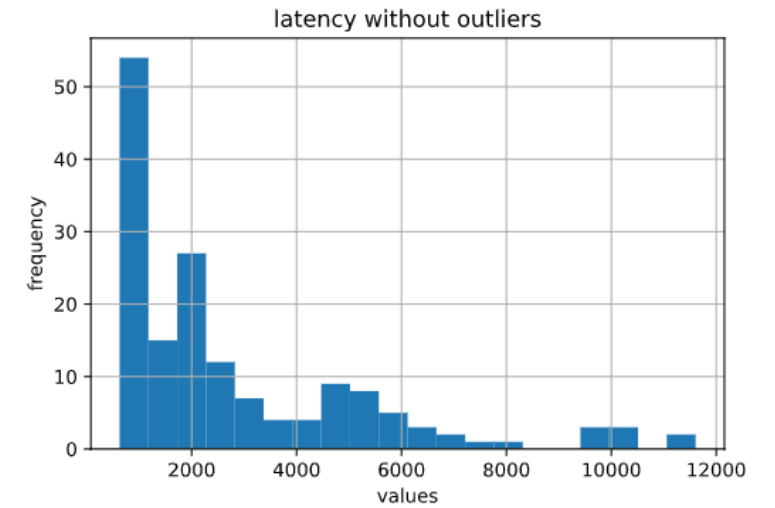
To code!

Latency Analysis

Note the unity of measure is microseconds (10^{-6} seconds)

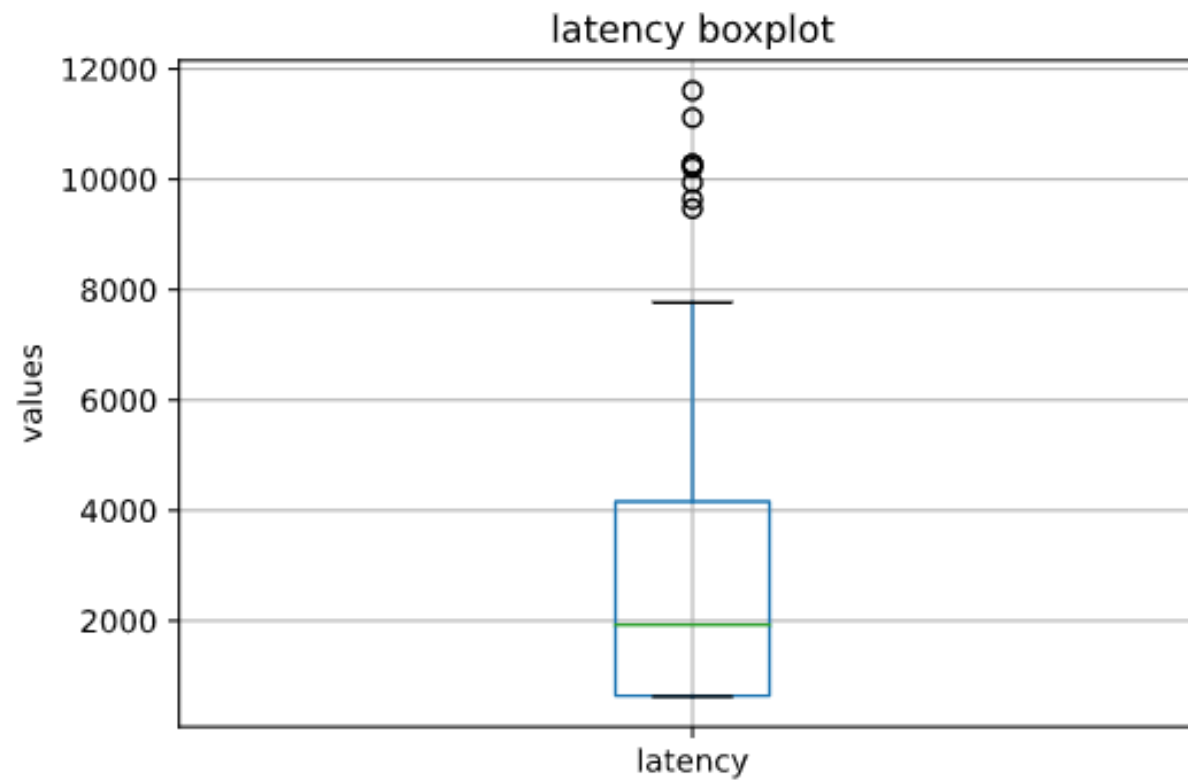


latency	
count	160.000000
mean	2725.993750
std	2517.251997
min	627.000000
25%	642.000000
50%	1926.000000
75%	4160.500000
max	11606.000000



Distribution

Median and Quantiles Representation



Median representation: is the number of samples big enough?

- We choose $r = 0.15$ and $1-\alpha=0.9$.

- This means $n = \left(\frac{Z_{0.45} \cdot s}{0.1\bar{x}} \right)^2 = \left(\frac{1.65 \cdot s}{0.15\bar{x}} \right)^2 \simeq 121 \frac{s^2}{\bar{x}^2}$

- Our test has:

```
mean = 2725.993750  
standard deviation = 2517.251997  
n = 160  
squared std/mean = 1.172725
```

- $121 \cdot 1.17 = 141.57 < 160$. So, our n is big enough!

Our Estimate For the Mean Latency

- We can say that, with 90% confidence: $\bar{x} - 0.15\bar{x} \leq \bar{x} \leq \bar{x} + 0.15\bar{x}$
- i.e., $2317 \leq \bar{x} \leq 3134$
- Moreover, our standard deviation is 2517 microseconds.