Towards AoI-Optimized Smart IoT Systems

*Sajjad Baghaee *, Hasan B. Beytur *, and Elif Uysal*

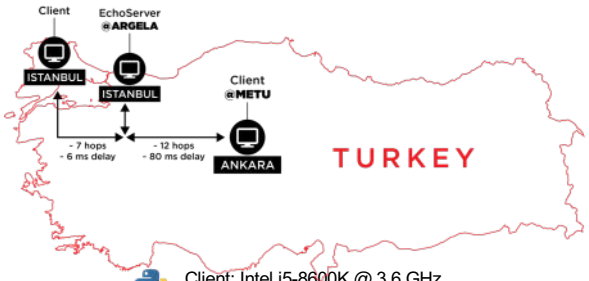
Overview

The goal of this work is to measure and ultimately control AoI on real-life links and end-to-end connections. Considering Internet of Things (IoT) implementations, reducing unnecessary ageing is important both for delivering fresh data to applications, and avoiding congestion. Both aims are vital for the energy efficiency at end nodes (typically sensors) and the scalability of multiuser links and networks to support the growing Internet of Everything.

The experimental results below indicate operating points in terms of sampling rate that mutually prevent ageing and waste of energy. It is also seen that operating outside these regimes can be detrimental.

Our Two Experiment Setups

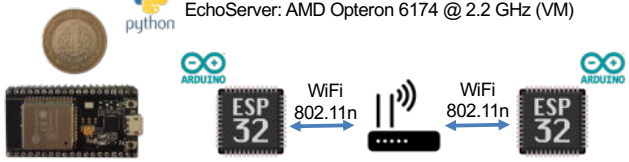
Internet based testbed



python

Client: Intel i5-8600K @ 3.6 GHz
EchoServer: AMD Opteron 6174 @ 2.2 GHz (VM)

IoT based testbed



NodeMCU ESP32: Xtensa® LX6 (600 MIPS)

Lightweight IP (LWIP) Stack for TCP&UDP

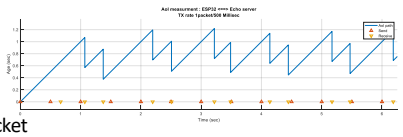
Definition: Age of Information (AoI)

- ***AoI is a metric to measure the freshness of the status update flow.***

$$\Delta_t = t - max\{S_i : D_i \leq t\}$$

Current time

timestamp of the freshest received packet



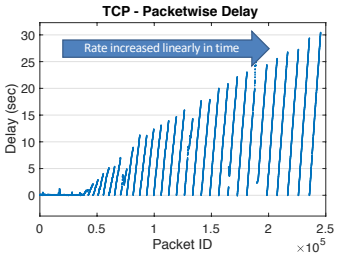
UDP and TCP Characteristics

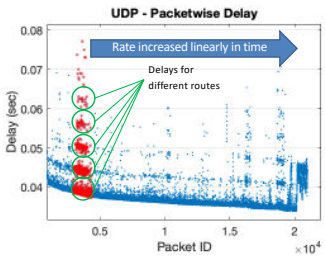
TCP (CUBIC)

- Increase in delay due to retransmission
- Congestion control (changing window)
- Requires ACKs
- Nagle's Algorithm (combining packets)
- Larger number of CPU cycles limits the number of packets per second

UDP

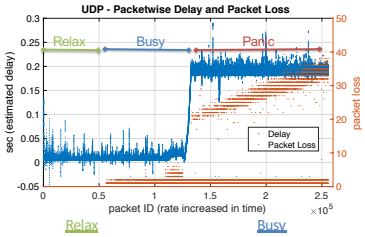
- Constant delay (no retransmission)
- Packet losses occur at high rates
- No ACKs
- Fewer of CPU cycles per transmission

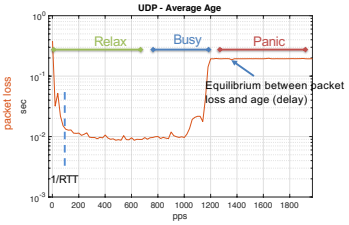




Average Age Behavior

- ***Measurements on the Internet***





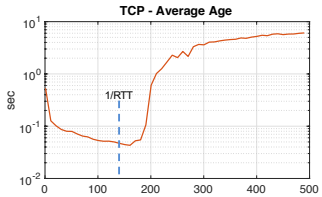
Relax
- Low delay
- Decreasing age
- No packet loss

Busy
- Moderate packet loss
- Increasing delay and age

Panic
- Increasing packet loss
- High delay
- Constant age

Bottleneck due to CPU: limited to max ~10000 packets per seconds (pps) = ~80 Mbps
Bottleneck due to Bandwidth: ~1000 pps = ~8 Mbps

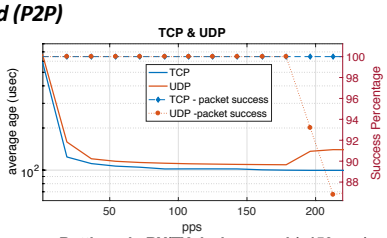
- High computational overhead on TCP.
- TCP suffers from retransmissions of old packets.
- Nagle's algorithm (combining update packets) is unsuitable for AoI



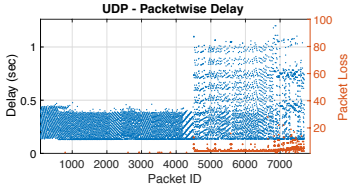
Bottleneck: RX device speed (~250 pps)

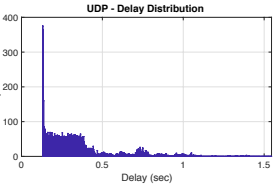
- ***Measurements on IoT Testbed (P2P)***

- TCP and UDP are limited by the IoT device's memory and computational power. (No threading on LWIP Stack)
- UDP suffers from packet loss when RX device is slower, so age increases.
- TCP operates at lower rates than UDP because of the dependency on ACKs.



Bottleneck: RX/TX device speed (~150 pps)





- LWIP Stack has problems with UDP → high delay variance (issues with buffer management)
- TCP is still better option for IoT.
- AoI increase at high rates was not observed, due to link delay being negligible (CPU becomes bottleneck)

Conclusions

- Age behavior is highly related with
  - The computational power of the device,
  - UDP/TCP buffers and packet sizes,
  - Bandwidth/RTT on links/connections.
- UDP is age-friendly at suitable rates.
- LWIP has to be modified to supply full performance on IoT devices.
- An age-aware transport/application layer mechanism could inherit congestion control from TCP and trade-off between age and packet loss.
- $\frac{1}{RTT}$ is a good operating point to start at (at least one packet in flight.)

Funded by: HUAWEI, TÜBİTAK, Türk Telekom, JEOIT

Department of Electrical and Electronics Engineering
Middle East Technical University
http://www.cng.eee.metu.edu.tr/
**: Both authors contributed equally to this study*