Ruin Theory Based Modeling of Fair Spectrum Management in LTE-U

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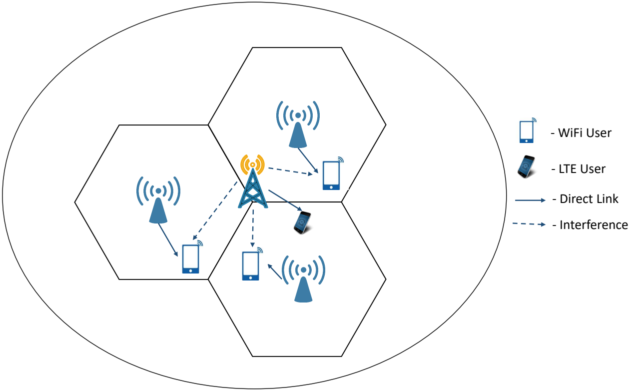
- Introduction
- System Model
- Ruin Theory
- Surplus Process for Wi-Fi Throughput
- Optimization Problem
- Results
- Results
- Conclusion

- With the increase in high data rate requirements in mobile networks, the surge for additional spectral resources has been increased significantly
- 5G cellular networks are looking for new spectrum resources to meet these future demands
- LTE unlicensed (LTE-U) provides the solution of spectrum scarcity by allowing LTE to coexist with Wi-Fi.
- LTE provides better spectral efficiency and is more BW hungry
- It can consume more BW which is unfair for Wi-Fi.
- We are aiming to apply Ruin Theory for fairness to Wi-Fi systems

- LTE-U is 5G technology proposed to solve the issue of spectrum scarcity in cellular networks
- The unlicensed spectrum is shared by LTE and existing WLAN technologies
- The goal is to maximize the spectrum efficiency without affecting the existing WLAN technologies

- There is one LTE SBS coexisting with multiple Wi-Fi APs
- There are $w \in \mathcal{W}$ Wi-Fi access points.
- $k \in c$ is the number of channels used by Wi-Fi system and can be allocated to LTE users



Our goal is to maximize the rate of LTE while providing fairness to Wi-Fi networks.

Problem Statement: Maximize the rate for cellular networks while satisfying

- Channel availability based on listen before talk (LBT)
- The probability of ruin for Wi-Fi is not much higher

- **LTE Users Data rate:**

$$r_i = \log_2\left(1 + \frac{p_i g_i}{\sigma^2}\right)$$

Where c_u is unlicensed spectrum from WiFi System.

- **Wi-Fi Throughput:**

$$r_w = \frac{P_{tr} P_s E[P]}{(1 - P_{tr}) T_\sigma + P_{tr} P_s T_s + P_{tr}(1 - P_s) T_c}$$

  - Where P_{tr} is probability of at least one transmission
  - P_s is probability of successful transmission
  - $E[P]$ is expected packet length
  - T_σ, T_s and T_c are duration of empty slot, successful transmission and collision respectively

- Ruin theory is the concept of classic economics where the insurance company decides the future premium rates using the probability of ruin
- This probability of ruin is obtained from the surplus process composed of
    - Initial investment of insurer
    - Regular premiums obtained from consumers
    - Random insurance claims from consumers
- The probability of ruin is defined as the probability of getting the net surplus negative

- Wi-Fi throughput is enhanced in each slot with successful transmission on available channels
- While it is reduced with each collision
- Surplus process for Wi-Fi can be modeled as

$$U(t) = \gamma + (ct)r_w - r_w^{'} \sum_{i=1}^{N_t} X_i$$

- $U(t)$ is Wi-Fi throughput Surplus.
- γ is initial throughput.
- c is the constant number of available channels and r_w is average throughput per channel.
- $\sum_{i=1}^{N_t} X_i$ is compound process of throughput reduction due to collisions.

- Probability of Ruin $\Psi(u)$ is defined as

$$\Psi(u) = P[U(t) < 0]]$$

- Ruin probability can be determined as

$$\Psi(x) = \frac{\lambda\mu}{c} \exp -(\frac{1}{\mu} - \frac{\lambda}{c})x$$

- λ is claim arrival rate (arrival rate for LTE resource allocation).
- μ is mean claim size (fraction of LTE resources).
- c is the the premium rate of Wi-Fi users.

- **Control Variables:**
  - $\alpha_k \in [0, 1]$ where $k \in \{0, 1, \ldots, c_u\}$
- **Parameters:**
  - Channel availability $\beta_k \in \{0, 1\}$
  - Probability of ruin for Wi-Fi throughput $\Psi(u)$
- **Optimization Problem:**

$$
\begin{aligned}
\max_{\alpha_k} \quad & \sum_{k \in c_u} \sum_{i \in u} \alpha_k \beta_k log(r_i) \\
\text{subject to} \quad & \sum_{k \in c_u} \alpha_k \beta_k \leq c_u \\
& \sum_{k \in c_u} \alpha_k \beta_k \leq (1 - \Psi(u)) \sum_{k \in c_u} \beta_k \\
& 0 \leq \alpha_k \leq 1
\end{aligned}
$$

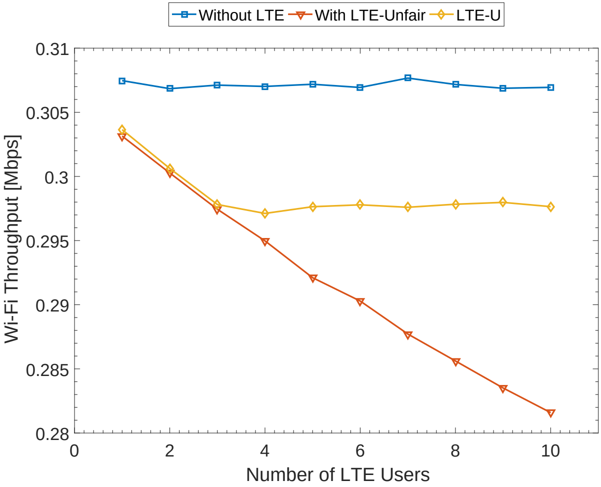
- Output of optimization problem is α_k which is proportion of each channel to be allocated to LTE users. r_b denotes the

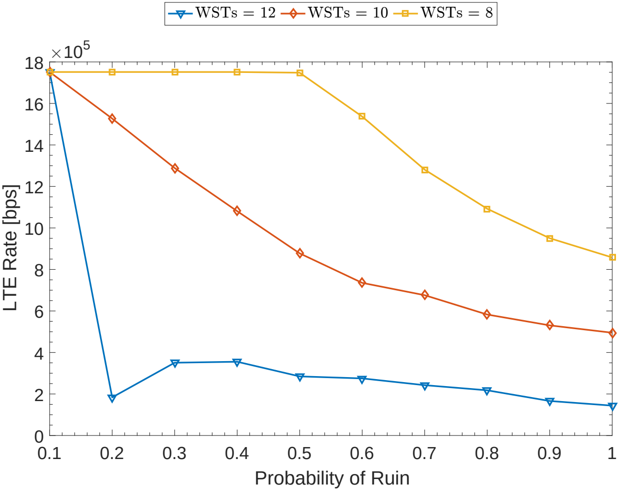
$$r_b = \frac{B_k \alpha_k}{N_{UEs}}$$

Where B_k is the unlicensed bandwidth of channel k and N_{UEs} is the total number of users.

- LTE rate can be found as

$$R_{LTE} = r_b \sum_{i \in N_{UEs}} log_2(1 + \frac{p_i g_i}{\sigma})$$


Without LTE
With LTE-Unfair
LTE-U
Wi-Fi Throughput [Mbps]
0.31
0.305
0.3
0.295
0.29
0.285
0.28
0
2
4
6
8
10
Number of LTE Users



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- This paper proposed a solution to provide fairness to Wi-Fi system by applying ruin theory.
- Surplus process for Wi-Fi throughput is modeled which is used to find the probability of ruin.
- Simulation results show resource allocation to LTE while providing fairness to Wi-Fi.

Thanks