IEEE Hong Kong 6G Wireless Summit

11-12 September 2024
Hong Kong, China

IEEE ComSoc IEEE Communications Society | IEEE

Department of Electronic and Computer Engineering

How Robust is Federated Learning to Communication Error? A Comparison Study Between Uplink and Downlink Channels

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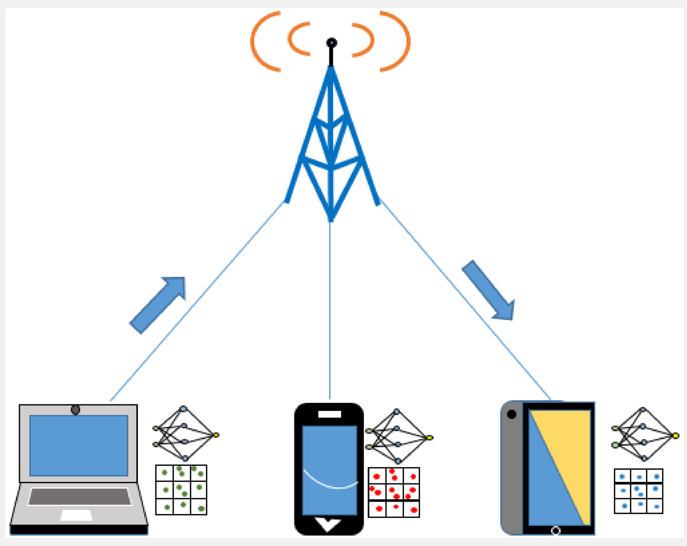
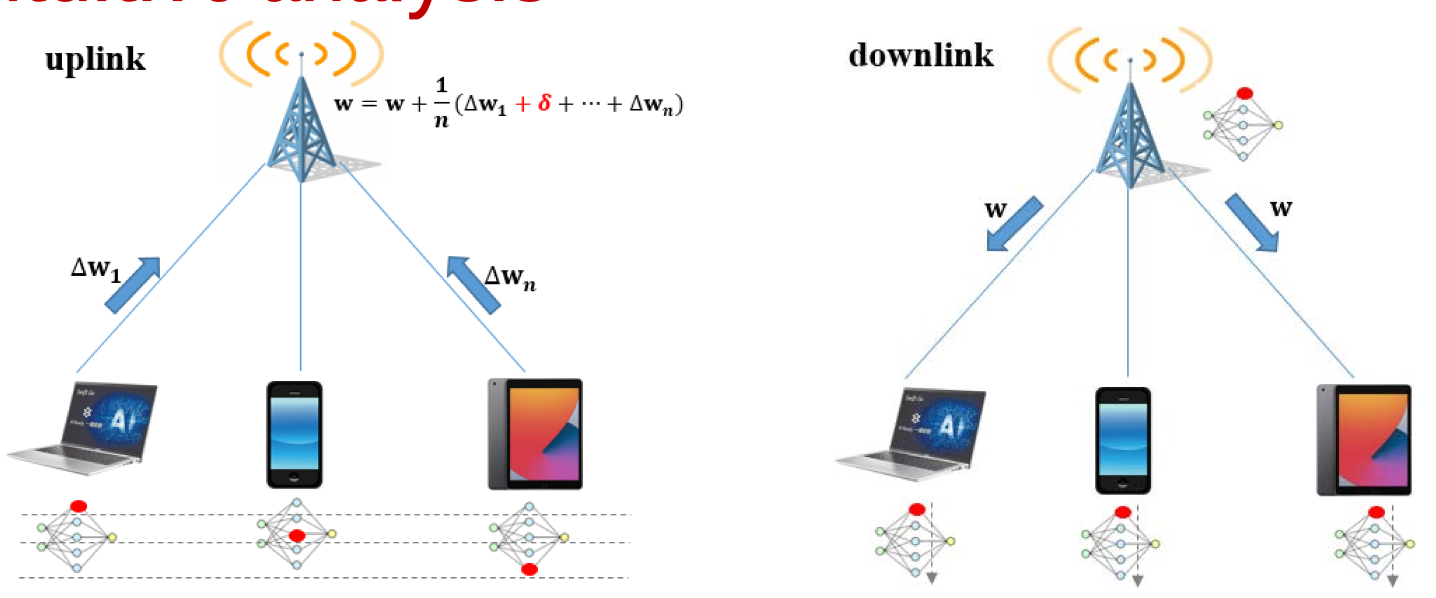
Motivation



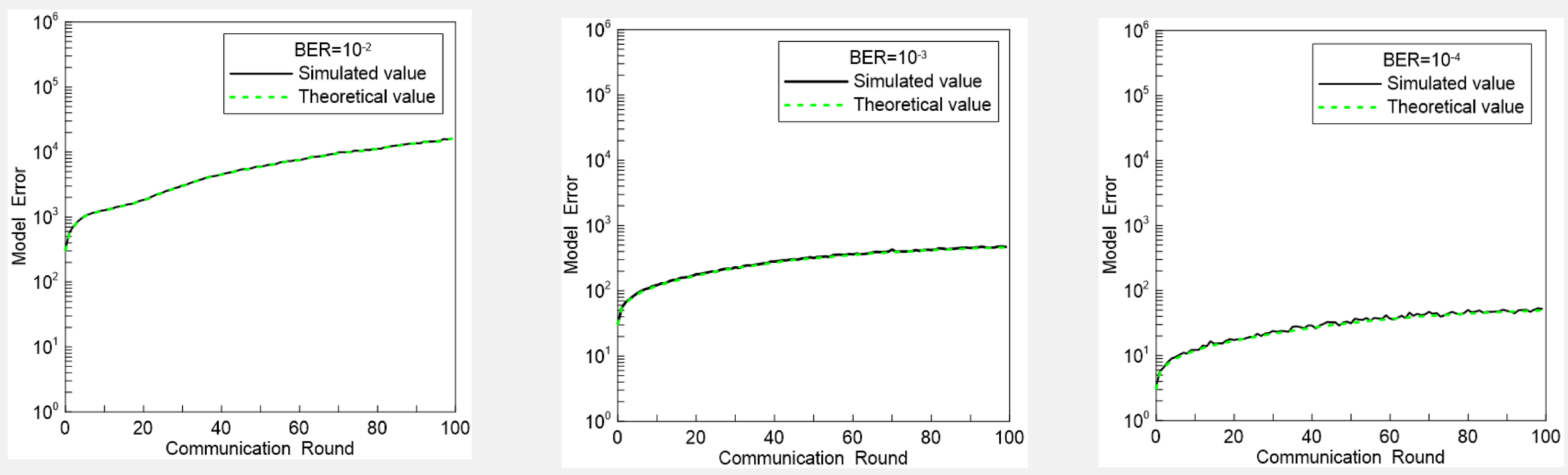
In wireless federated learning, the learning performance is affected by the communication errors in both uplink and downlink channels. This study is going to investigate the robustness of federated learning to communication errors, especially to find the difference between uplink and downlink in case of the error tolerance.

Intuitive analysis



For uplink, the errors usually occur in different DNN parameters for different clients. When aggregated in uplink, the error will be averaged. But for downlink, the errors in global model will just be broadcast to clients and propagated in local training. So uplink should tolerate higher BER than downlink.

Theoretical analysis



The relationship between model error and BER:

$$E\|\mathbf{w}'-\mathbf{w}\|^2 = \frac{d(4^N-1)b(1-b)^{N-1}\cdot range(\mathbf{w})^2}{3(2^N-1)^2}$$

The relationship between FL convergence and BER:

FL with uplink BER:

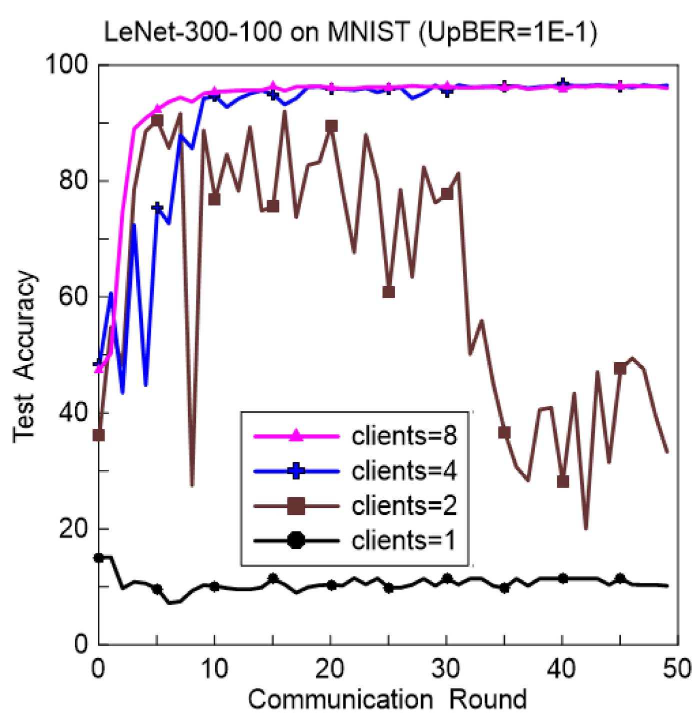
$$\frac{1}{K\tau}\sum_{m=0}^{K-1}\sum_{t=0}^{\tau-1} E\left\|\nabla f(\overline{\mathbf{w}}_{m,t})\right\|^2 \le \frac{Ld}{3n^2K\tau}\sum_{m=0}^{K-1}\sum_{i\in[n]}\left[BER_m^i\cdot range^2(\Delta\mathbf{w}_m^i)\right] + \frac{2(f(\mathbf{w}_0)-f^*)}{K\tau\eta} + \frac{L^2(n+1)(\tau-1)\eta^2\sigma^2}{n} + \frac{L\eta\sigma^2}{n}$$

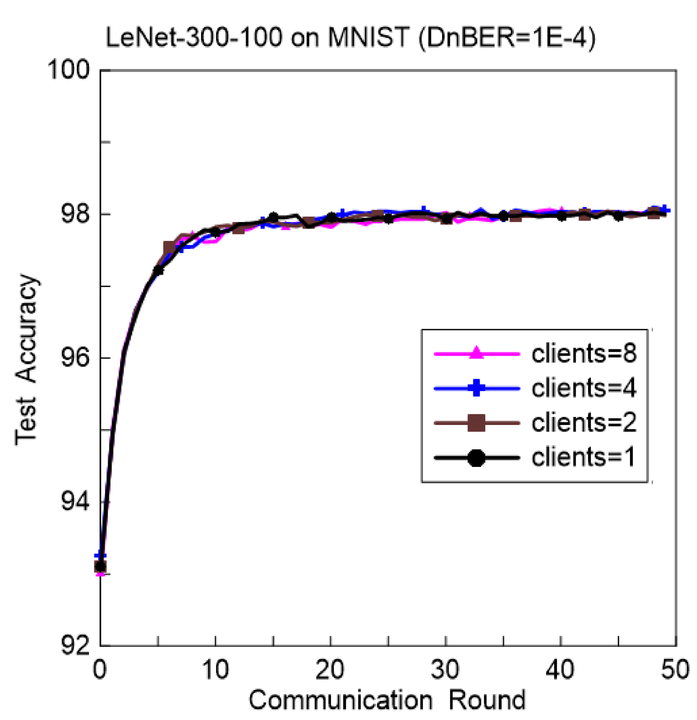
FL with downlink BER:

$$\frac{1}{K\tau}\sum_{m=0}^{K-1}\sum_{t=0}^{\tau-1} E\left\|\nabla f(\overline{\mathbf{w}}_{m,t})\right\|^2 \le \frac{2Ld}{3K\tau\eta}\sum_{m=0}^{K-1}\left[BER_m\cdot range^2(\mathbf{w}_m)\right] + \frac{2(f(\mathbf{w}_0)-f^*)}{K\tau\eta} + \frac{L^2(n+1)(\tau-1)\eta^2\sigma^2}{n} + \frac{L\eta\sigma^2}{n}$$

Simulation

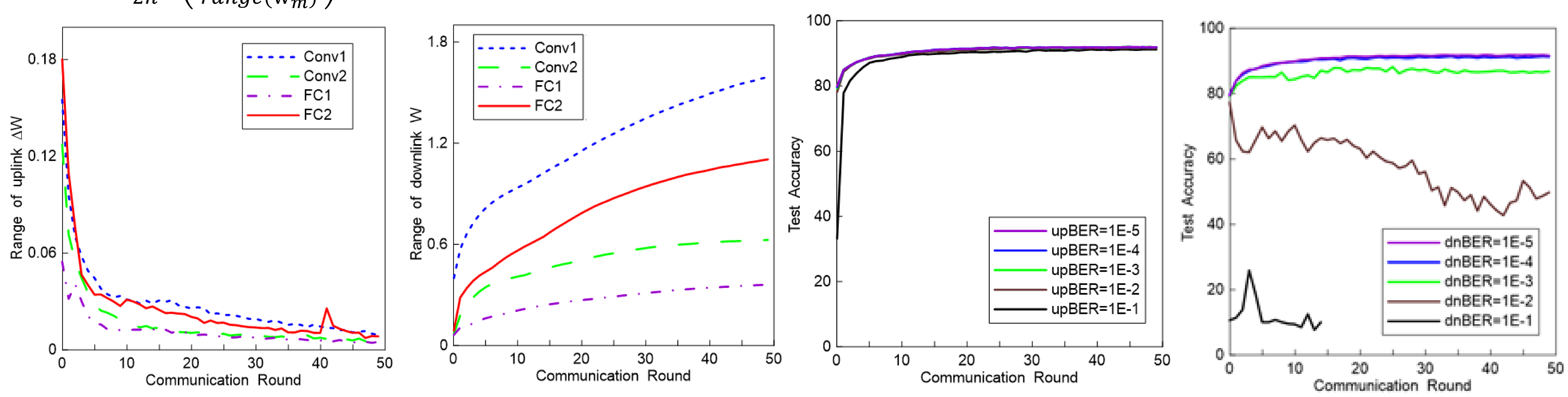
Validate the effect of n:
Client number n should help to reduce the uplink error but not for downlink error.





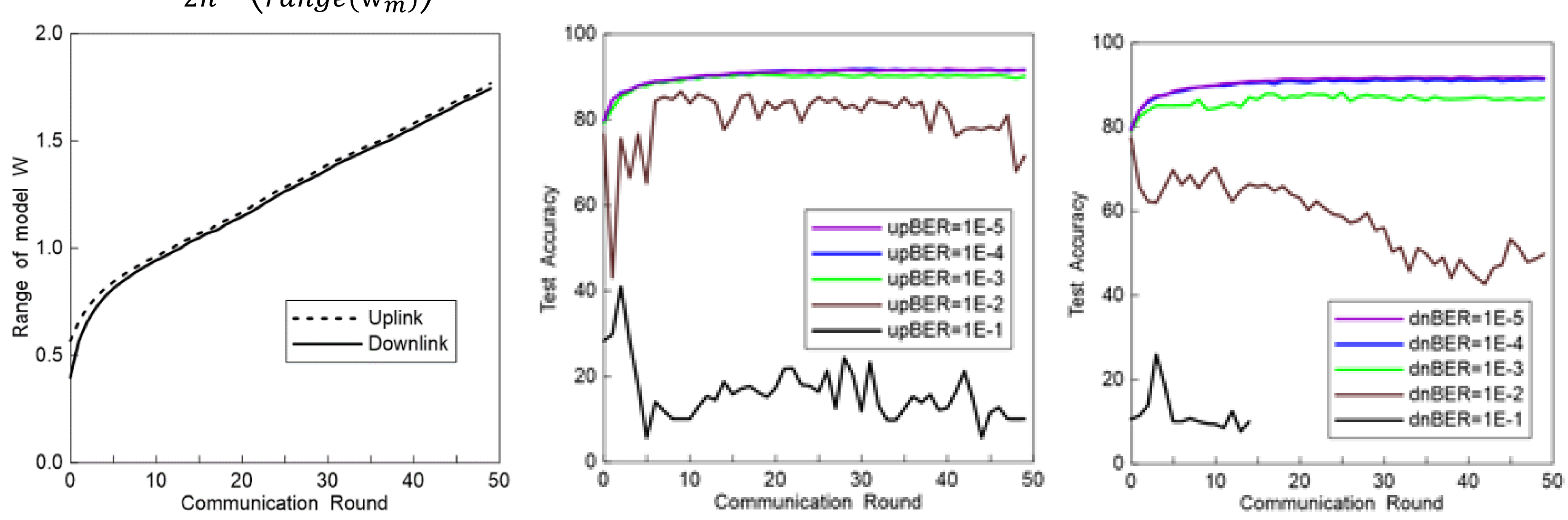
If gradients are transmitted in uplink, to achieve the same learning performance, it should satisfy

$$BER_m = \frac{BER_m^i}{2n}\left(\frac{range(\Delta w_m^i)}{range(w_m)}\right)^2$$



If weights are transmitted in uplink, to achieve the same learning performance, it should satisfy

$$BER_m = \frac{BER_m^i}{2n}\left(\frac{range(w_m^i)}{range(w_m)}\right)^2$$



We find that uplink tolerates higher BER than downlink. And we get the theoretical explanation which is further validated by simulations.

[1] L. Qu, and etc, “How robust is federated learning to communication error? a comparison study between uplink and downlink channels,” in Proc. IEEE WCNC, Dubai, UAE, April. 2024.

Acknowledgment

This work was supported in part by the Hong Kong Research Grants Council under the Areas of Excellence Scheme Grant AoE/E-601/22-R