Performance Study of Statistical and Deterministic Channel Models for mmWave Wi-Fi Networks in ns-3

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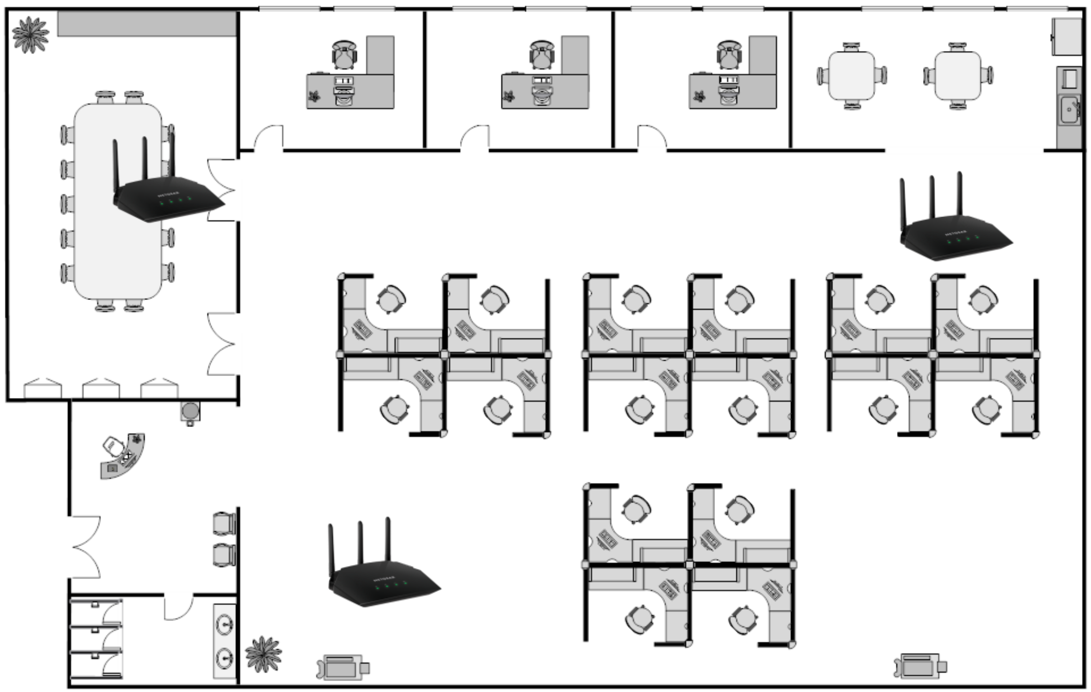
MmWave Wi-Fi Networks

- Large amount of bandwidth available to support high-rate applications
- Challenges to overcome: range-limited & blockage-prone



- The blockage sensitivity, use of directional antennas, and multi-path sparsity nature make the channel modeling more complicated.

Channel Models in mmWave Networks

- **Log-distance based channel model**

  -- based on propagation and a single random variable for fading

  -- hard to accurately model multi-path components

- **Statistical channel model**

  -- describes the stochastic characteristic of amplitudes of the resolvable MPCs and path time of arrival

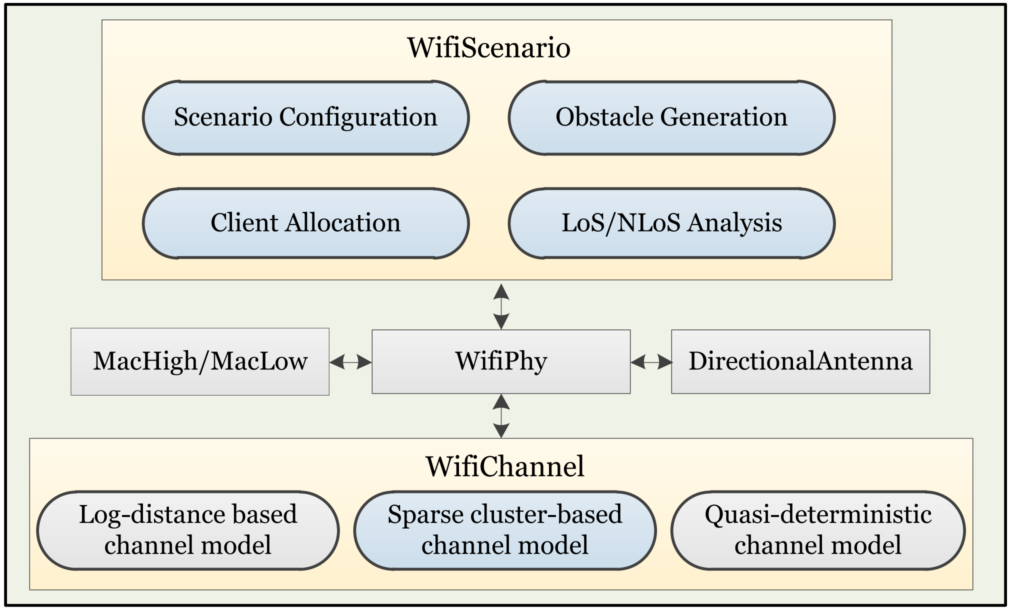
- **Ray-tracing based channel model**

  -- precisely model the propagation of wireless signals in specific sites and scenarios

Performance study on mmWave WLAN with statistical and ray-tracing-based channel models

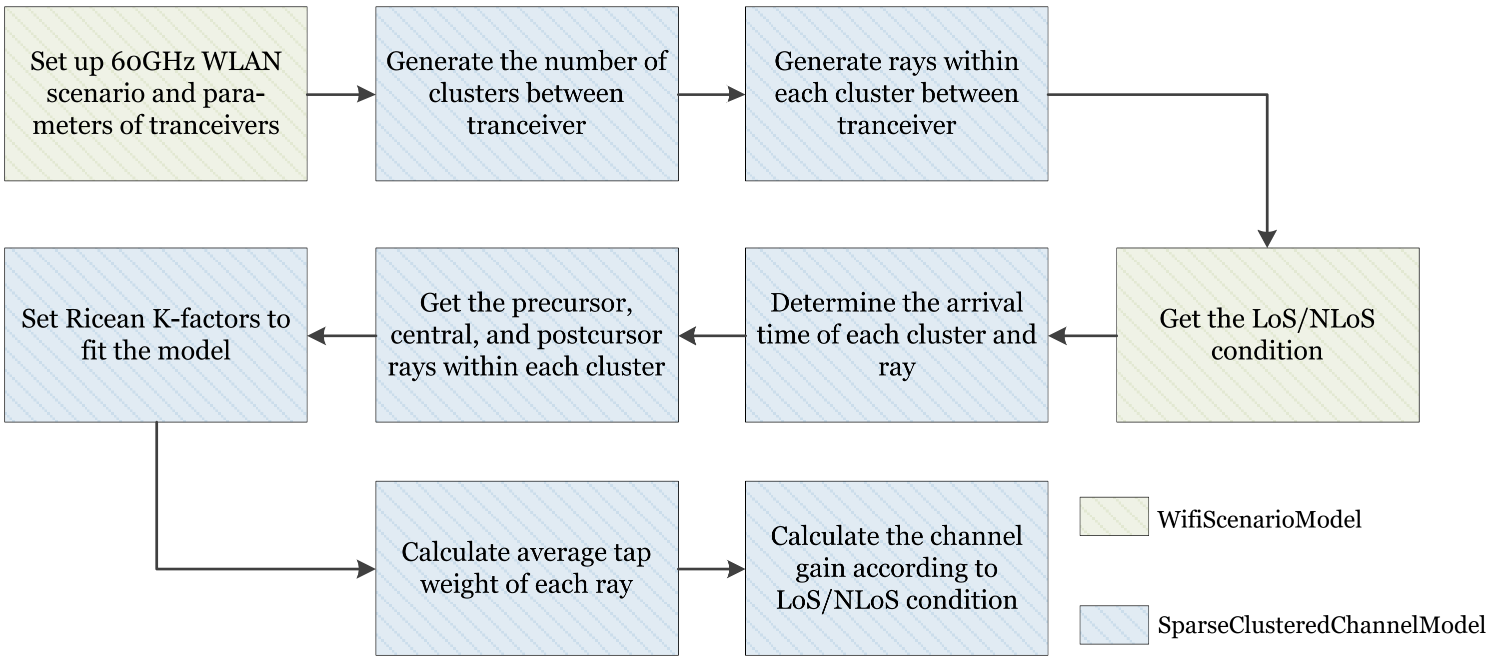
ns-3 Implementation

- **Obstacle-specific scenario model**
  - scenario configuration, obstacle generation, client allocation, LoS analysis
- **Sparse cluster-based channel model**
  - a statistical channel model for 60 GHz WLAN



Sparse cluster-based (SC) channel

- Saleh-Valenzuela channel model: inter-cluster, intra-cluster, pre-/post-cursor
- Parameters for power delay profiles, w.r.t., frequency, environment, LoS/NLoS.

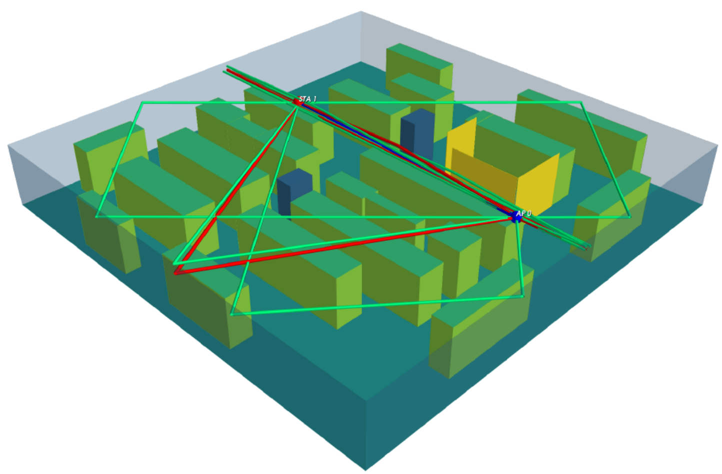


Quasi-deterministic (QD) Channel

- Generate WLAN scenario with multiple objects in the room, and valid locations of APs and clients.
- NIST Q-D channel realization software [1] in MATLAB to generate the spatial channel matrix between every node in the scenario.

  -- MPCs, pathloss, phase shift, delay profile, AOA, AOD, etc.

- ns-3 802.11ad Q-D model [2], which parses the ray-tracing results and computes the channel gains.



[1] A. Bodi, etc., "NIST Quasi-deterministic Channel Realization Software Documentation", 2021.
[2] H. Assasa, J. Widmer, T. Ropitault, and N. Golmie. Enhancing the ns-3 IEEE 802.11ad Model Fidelity: Beam Codebooks, Multi-antenna Beamforming Training, and Quasi-deterministic mmWave Channel., 2019.

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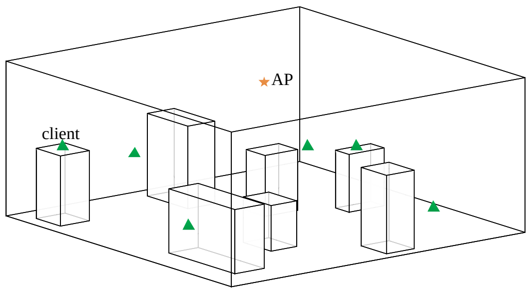
Simulation Settings and Metrics

- **Room configuration**: 12m*8m*3m;
- **AP deployment**: Optimal multi-AP placement method from [1];
- **Obstacle model & Client model**:
  1) random generation modes for obstacles;
  2) client locations are generated following the uniform distribution within the room.
- **Channel models**:
  SC channel vs. QD channel.



- **Performance metrics**:
  1) performance difference ratio (PDR): $$PDR = \frac{|Th_{SC} - Th_{QD}|}{Th_{max} - Th_{min}}$$
  2) simulation runtime.

[1] "Optimal Access Point Placement for Multi-AP mmWave WLANs", ACM MSWiM, 2019.

Evaluation Results

- **Comparison between SC and QD channel models**

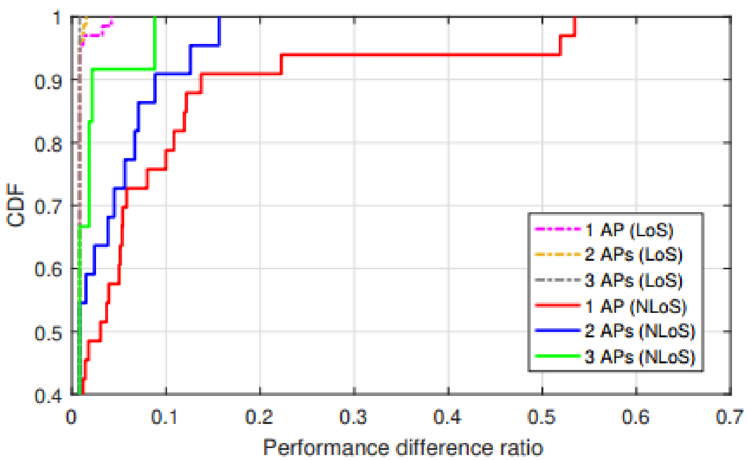


Figure CDF of PDR for LoS and NLoS Links and a Varying Number of APs

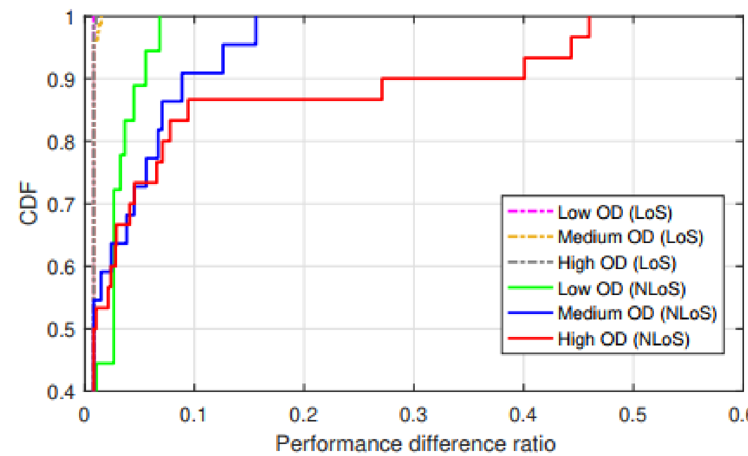


Figure CDF of PDR for LoS and NLoS Links and Varying Obstacle Density

- The two different models produce nearly identical throughputs under LoS conditions.
- For the majority of NLoS cases, the SC model results in a throughput that amounts to at most a difference of one MCS level as compared to QD model.
- Multiple APs and lower obstacle density reduce the difference between the two models substantially.

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Evaluation Results

➢ **Parametric analysis of SC channel model**

- the expected number of clusters L and rays N within each cluster: (2, 6) **->** (3, 8)

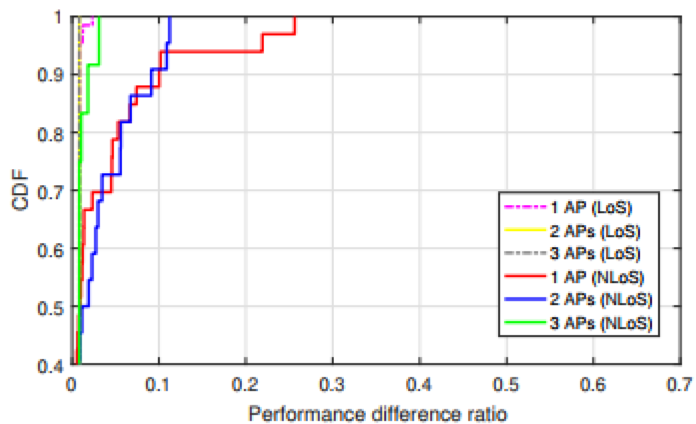

Figure CDF of PDR for Varying Number of APs with Tuned Channel Parameters

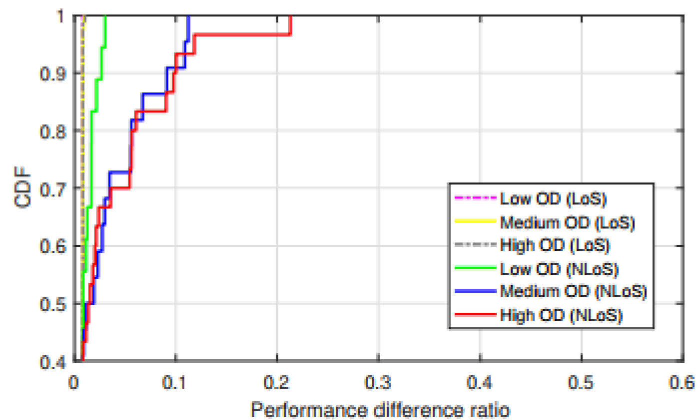

Figure CDF of PDR for Varying Obstacle Density with Tuned Channel Parameters

- Increasing the expected number of clusters and rays in SC channel model can improve the accuracy of the SC model.
- The throughput under the SC channel model is within about 1.5–4% of the QD channel model's throughput when averaged over 20 client locations, even for the worst case scenario and only considering the difficult NLoS cases.

Evaluation Results

- **Parametric analysis of SC channel model (cont'd)**
  - Tune the expected number of clusters L and rays N within each cluster

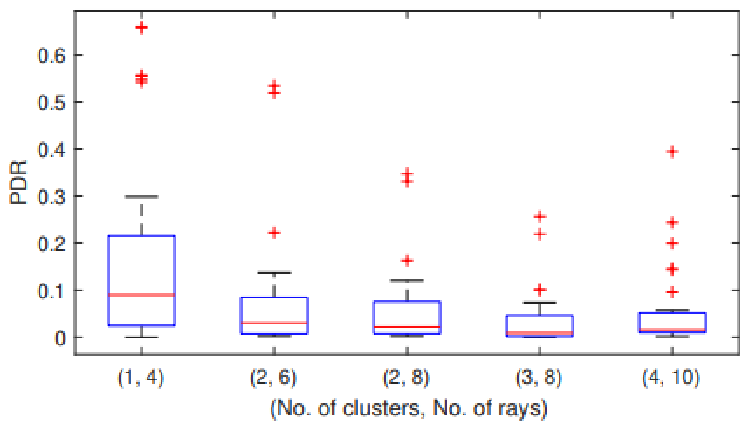

Figure PDR for Different SC Channel Parameters and NLoS Instances Only (Case 1)

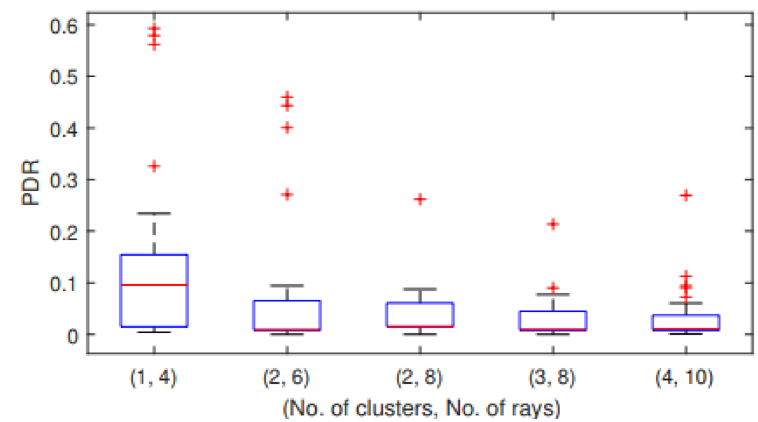

Figure PDR for Different SC Channel Parameters and NLoS Instances Only (Case 2)

- Properly tuning $\boldsymbol{L}$ and $\boldsymbol{N}$ can make a good agreement with the ray-tracing-based QD channel model.

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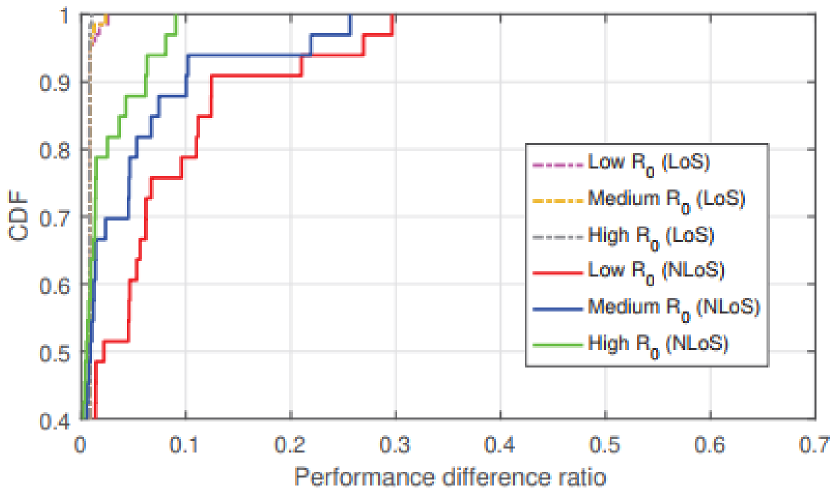
Evaluation Results

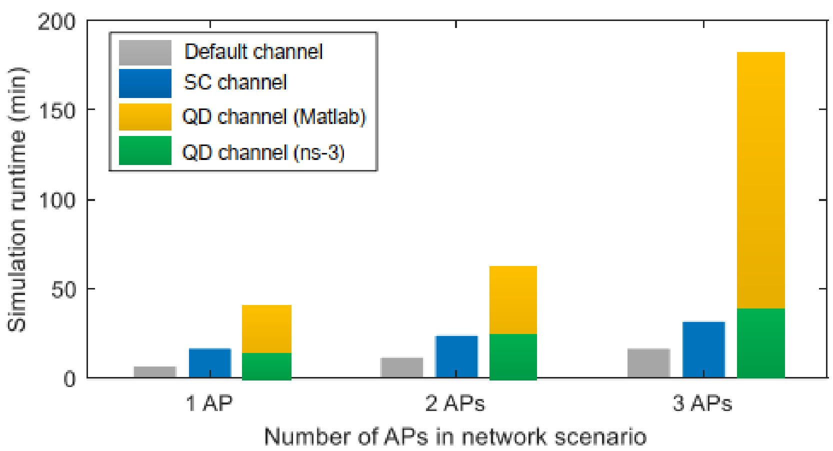
➢ **Comparison Between SC and QD Channel for Different Reflectivities**

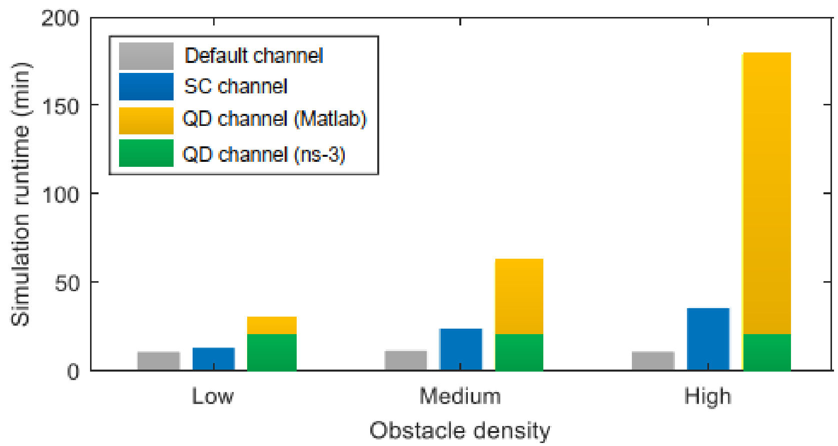


- The performance difference becomes smaller between the two channel models with the higher reflectivity mode.
- At low reflectivity, the performance gap gets slightly larger than at medium reflectivity for this problematic case (1-AP, medium obstacle-density case).

Evaluation Results

➢ **Computation efficiency for SC and QD channel models**





- In comparison to default log-distance based model, there is roughly a 2x slowdown for SC model. For low obstacle densities, the slowdown is slight.
- The running time with the SC channel model increases much more slowly as the number of deployed APs or the obstacle density increases, as compared to the QD model.

Summary

- Implemented additions to the ns-3 802.11ad simulator that include 3-D obstacle specifications, line-of-sight calculations, and a sparse cluster-based channel model.

- Studied the performance accuracy and simulation efficiency of the implemented statistical channel model as compared to a deterministic ray-tracing based channel model.

  -- The implemented statistical channel model has the potential to achieve good accuracy in performance evaluation while improving simulation efficiency.

  -- Provide a detailed parametric analysis on the statistical channel model, which yields insight on how to properly tune the model parameters to further improve accuracy.

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Thanks!