Millimeter Wave Communications: From Point-to-Point Links to Agile Network Connections

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The Problem Definition:

Millimeter wave technologies are revolutionizing wireless networks (especially 5G) by providing significant improvements such as high data rates, reduced dropped connections, reliability, and efficiency. But the key challenge with mmWaves is that these signals attenuate quickly with distance (due to low wavelength) which makes their integration with cellular or 802.11 networks tricky. The existing radios scan the entire space to find the best alignment between the transmitter and receiver which is a time-consuming activity and adds to the setup delay and switch latency when the base station switches between the users and mobile client. The paper presents a solution, named Agile-Link to solve this problem of steering by eliminating the scanning and introducing the hashing technique on the beam directions.

Key Idea:

Agile-Link evaluates the phase arrays and demonstrates finding the correct beam alignment without sequentially scanning the space. The whole system relies on the hashes and voting mechanism and the fact that there are only a few paths that the mmWave signals can take between the transmitter and receiver. Agile-Link works on hashing these limited spatial directions into bins where each bin collects energy from many directions. It then ignores all the bins with no energy and only focuses on the bins with high energy, this is performed multiple times by randomizing the hashes to avoid ignoring the signals/bins that have negligible energy due to signal strength degradation (due to factors like multipath as well as high SNR). Then a voting mechanism is applied to the resultant signals to recover the directions that have the energy.

Important Details:

1. We can only control the phases on each antenna in the phased array and nothing (like size, frequency, etc.) else can be changed hence Agile-link focuses on finding the setting of the vector that creates good beam patterns which can hash the space into bins and cover the entire region; create beam patterns that can be randomized to change the different directions that hash to the same bins.
2. Agile-Link divides the antenna array into sub-arrays and makes each sub-array beam toward a different direction.
3. The direction in which the sub-array directs its beams is best when the leakage from the side lobes of the beams is minimized.
4. A soft voting approach is used to take the leakages between the bins into account. This approach considers the probability of the angles at which the received signal will be received and the maximum energy.
5. Agile-Link's algorithm relies only on the magnitude of the measurements to recover the correct beam alignment and hence does not suffer due to carrier frequency offset.

6. Agile-Link claims to reduce the search time by 1 to 3 orders of magnitude, for array sizes that range from 8 antennas to 256 antennas. In comparison to the quasi-omnidirectional search, Agile-Link reduces the delay by 1.5 times to 10 times.

My Thoughts and Criticism:

The paper indeed presents some great work in the field with relevant observations and theoretical proofs. The paper provides a simplified example for the reader to understand the concept and is well-written in a short, crisp, and detailed way demonstrating a great mindset. The author has tried to be very open about his ideas and thought process on all the factors and observations. Honestly, this paper was good learning for me.

However, a few of the assumptions and scenarios that led me to question/confusion are:

1. Even though the paper tries to improve the latency between the switch (in the case of mmWave) still the complexity of computation of the final signal post-voting is quite high $O(K^2 \log N^2)$.
2. What if the frequency of the input mmWave is increased, how will it impact the observations? All the observations mentioned in the paper are taken on the 24GHz ISM band.
3. The experiment setup could be extended to a more real-time setup and not just office space. Although, the author states to have performed certain simulations.
4. Agile-Link significantly relies on the concept of performing the hashing while randomizing the directions under that same bin. Will this work when the bins are scaled up? I mean will it not increase the error possibility with scaling?
5. The impact of change in network bandwidth, and energy & power consumption is not considered while performing the experiment. Because if we consider scaling up these factors could impact the practical implementation of the solution.