Before the

FEDERAL COMMUNICATIONS COMMISSION

Washington, D.C. 20554

In the Matter of	)	
	)	
Use of Spectrum Bands Above 24 GHz For Mobile Radio Services	)	GN Docket No. 14-177
	)	
Amendment of the Commission's Rules Regarding the 37.0-38.6 GHz and 38.6-40.0 GHz Bands	)	ET Docket No. 95-183 (Terminated)
	)	
Implementation of Section 309(j) of the Communications Act – Competitive Bidding, 37.0-38.6 GHz and 38.6-40.0 GHz Bands	)	PP Docket No. 93-253 (Terminated)
	)	
Petition for Rulemaking of the Fixed Wireless Communications Coalition to Create Service Rules for the 42-43.5 GHz Band	)	RM-11664

1. Introduction

We welcome the interest of the FCC towards the millimeter wave (mmWave) bands. Substantial amount of interest in mmWave has been shown yet the technical contributions have been limited to a handful of submissions.

In this response, we comment on several technical items of interest related to the deployment of mmWave for 5G mobile communication.

2. Importance of blockage

There are several important sources of blockage in mmWave systems: (i) buildings, (ii) people in the propagation channels, (iii) the user's own body, and (iv) the user's hand or fingers. Measurements show that mmWave does not penetrate very well materials that are typical for outer walls of buildings [1]. This means that indoor coverage from outdoor infrastructure will be challenging. There are substantial differences in the path loss conditions between line-of-sight and non-line-of-sight links. Buildings tend to block the line-of-sight link, forcing the link to operate in the less optimal line-of-sight mode [2]. Human bodies, either people in the environment or user's own, can also block the best path and further can cause 20-40 dB attenuation in signal power [3]. Moreover, the blocking from human body is different from that from buildings, as it can be time-varying as people change positions. Similarly, fingers of users can also block certain antenna elements of the cell

phone, and change the antenna geometry [4]. The blockages from a human body and fingers will add uncertainties to the channel model, and will require more robust design of transmission techniques.

Some potential solutions have been suggested to overcome challenges due to blockage. For blockage effects from buildings, prior work show that with dense base stations, the coverage in mmWave can be even better than the conventional networks; as the blockages also attenuate interference. Techniques to exploit macro-diversity, including base station coordination and fast beam switching, have been suggested to overcome the blockages effects from human bodies with potential movement [5]. For the finger blocking, one promising solution is to deploy multiple antenna arrays on the mobile stations to increase receiver diversity, which is feasible due to the small wavelength at mmWave frequencies [4].

In summary, we believe that blockage will be a significant but solvable challenge for cellular systems operating at mmWave frequencies. We have made progress on understanding the impact of blockages on system performance, and believe that the impact of blockage can be overcome through careful system design and therefore blockage is not insurmountable.

3. Coverage of mmWave Cellular Systems

One key issue in the deployment of mmWave for cellular networks is if they can provide reasonable system coverage, given the significance of blockage due to buildings and people. We have been studying coverage in mmWave cellular networks in [6-10]. Our approach considers blockages due to buildings as found in urban areas and looks at adaptive directional antenna at both the base stations and the mobile equipment. Based on the proposed model, we investigated different performance metrics related to coverage and rate outage in mmWave cellular networks as a function of the base station density, building statistics, and beamforming geometry. Our results indicated that due to the presence of blockages, the coverage performance in mmWave networks is very sensitive to the base station density. The coverage tends to be poor when the base station density is low relative to the density of buildings, as intuitively there will be coverage holes surrounded by buildings, where signals are heavily attenuated. Coverage becomes better when the base station deployments are denser. In our simulations, we found that in typical urban areas inter-site distances of less than 200m were needed to obtain reasonable coverage. Moreover, our analysis shows that the optimal base station density should scale with building density. In terms of rate coverage, we find that mmWave systems can provide comparable or even better spectrum efficiency than the conventional systems with sufficiently dense base stations, which translates into much higher data rates providing large spectrum is allocated for mmWave cellular.

In summary, mmWave cellular system deployments will have to be dense to provide good coverage in urban areas. With enough density, such networks can offer better spectral efficiency and much higher data rates than systems operating at conventional cellular frequencies.

4. Sensitivity to Interference

Different claims have been made in prior work about the sensitivity of mmWave networks to interference. Some work argues that they will be largely noise limited [11-13] while other work argues they will be interference limited [7]. We believe that both solutions are possible, with the answer depending very carefully on the type of antenna arrays, the resulting beamwidths, and the density of the deployment.

For example, in related work we derived a tight approximation on the instantaneous interference to noise ratio (INR) for outdoor mmWave device-to-device networks [14]. We incorporate mmWave features by using directional beamforming and accounting for the difference between LOS and NLOS interference. We showed that in dense networks the interference power is nearly always higher than the noise power. For example, if the system beamwidth is 30 degrees, which is a reasonable assumption for mobile devices, the interference is greater than the noise 50% of the time if users are, on average, 50 meters apart. For sparse networks with narrow antenna patterns, we confirmed that the network was indeed noise limited. It should be noted that the expected operating beamwidth will depend on the carrier frequency since more antenna elements can be packed in the same space at high frequencies and used to create a narrower beam pattern. The noise power is a function of the spectrum allocated: larger spectral channels will have more noise power.

In summary, we believe that interference still has a role to play in mmWave systems. With some choices of parameters the interference may not be significant while with other choices of parameters the interference may be significant. This effect is important as the FCC considers different spectrum sharing models. More work is needed to understand how mmWave cellular systems might interfere with other services sharing the same bands.

5. Antenna Array Technology

Beamforming in outdoor mmWave systems will be critical in overcoming high path-loss and achieving reasonable link budgets. Large beamforming gains are made possible by the fact that, at mmWave frequencies, large antenna arrays can be packed into small form factors. Unfortunately, the high cost of mixed signal components, like high-resolution analog-to-digital converters, makes it difficult to dedicate an RF chain per antennas and to make all the antenna processing entirely in the baseband domain, as traditionally done in low-frequency systems. Hence, different transceiver architectures have been developed to make use of the large arrays in a power-efficient way.

Hybrid analog/digital architectures, which divide the precoding processing between analog and digital domains is a one promising candidate for mmWave systems [15-19]. In hybrid architectures, the transmitted/received signal is processed in two stages: One processing stage in the baseband/digital domain and the other stage in the RF domain using a network of phase shifters. Thus, the hybrid architecture offers more freedom to take advantage of spatial multiplexing that is so powerful in a MIMO (multiple input multiple output) wireless systems. This enables more sophisticated multi-stream and multi-user precoding schemes to be realized using mmWave-suitable hardware. In our work, we developed hybrid

analog/digital precoding techniques for single-user and multi-user systems [17,18], and showed that the performance of these schemes approach that of fully-digital unconstrained solutions while accounting for the different hardware constraints in mmWave systems.

In summary, new array architectures will be needed for mmWave systems, but there is already ample evidence that such architectures are practically feasible.

6. Potential for Shared Access

Since mmWave communication is highly directional, the interference from nearby BSs is not severe. This brings the possibilities of allowing BSs of different networks to share the spectrum even when there is no coordination with a small degradation in performance. Hence in mmWave there is a need to study the optimal licensing scheme to maximize spectrum utilization and performance.

One simple licensing scheme is the conventional UHF licensing where the networks are provided exclusive licenses. To increase the spectrum utilization, secondary users could be allowed to transmit if they can do so without interfering the primary licensees. However this will require extensive coordination or even need of third party databases to provide reliable performance to the primary licensees. Another licensing scheme is to let networks share a spectrum with some level of coordination and resource sharing. In mmWave this seems especially attractive because due to directional beamforming, it may be possible for even co-located infrastructure to share the same spectrum without causing too much interference.

We believe that an extensive study is needed to understand the trade-off between spectrum sharing and performance degradation to help devise the optimal licensing schemes. This is an important area for further study.

7. Conclusions

We thank the Commission for providing the opportunity to publically comment on the viability of mmWave technology for next-generation wireless applications. Certainly, the engineering and regulatory hurdles must be surpassed, but we firmly believe that mmWave spectrum is vital to the continued expansion and innovation within the wireless industry.

Respectfully Submitted,

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