First Measurements of Cloud-RAN LTE Smallcells in an Indoor Stadium

Jay Weitzen, Nathan Sutter, Rachel Wakim, and Ali Alkhatabih

***Abstract*—Indoor smallcell technology is generally associated with residential and small business applications. Due to the need for many smallcells to cover a large venue such as an arena or stadium, the mutual interference and handoffs between standalone smallcells make this technology less than optimal for this type of deployment. For large indoor venues such as arenas, distributed antennas are the preferred technology, albeit expensive to deploy. This paper presents the first live-network measurements, in a 7500 seat arena venue, of a new IP-based "cloud RAN" smallcell technology that creates a single LTE cell from a group of distributed radio points. The single virtual cell architecture eliminates the intercell borders, providing very high-quality uniform coverage in a large venue. High-resolution measurements of key LTE parameters including RSRP, SINR, CQI and MCS were collected using an automated robotic coverage system and are compared to predictions.**

***Index Terms*—Smallcells, Femtocells, LTE**

I. Introduction

Indoor smallcells, also known as femtocells, possess most of the capabilities of conventional macrocellular base stations, but operate at much lower powers than macrocellular base stations (10-23 dBm versus 40-43 dBm) and generally support fewer users. A large body of literature has developed over the past few years describing smallcell technology [1, 2, 8, 9, 10]. Historically, indoor smallcells have been used in residential and small enterprise applications consisting of at most a few smallcells to provide high quality indoor coverage where there is limited macrocellular coverage and to provide macrocellular offload. Indoor smallcells can typically cover between 2000-12,000 square feet or approximately 300-1000 square meters, depending on the layout of the building, how many walls are penetrated, and the building materials. Wireless operators have already deployed millions of residential smallcells in the US, Europe and Asia [10]. With classic smallcell technology, each smallcell functions as an independent standalone cellular base station, and because of this mode of operation, clusters of conventional smallcells tend to create mutual interference resulting in poor signal-to-noise ratio and throughput at the inter-smallcell boundaries. The relatively small coverage footprint of the individual smallcells, combined with the resulting mutual interference, poor throughput, and high signaling loads at the borders due to inter-smallcell handoffs, have discouraged their use in relatively large venues requiring deployment of more than a few smallcells. The problem of intercell borders in a dense deployment of smallcells is illustrated in Figure 1a.

In practice, the conventional solution for providing coverage in large open venues, such as a stadium or arena, is a distributed antenna system (DAS) connected to one or more macrocellular base stations. The deployment model can be either an active DAS with distributed amplifiers and radio heads or a passive DAS made up of RF cables, splitters and localized antennas [4]. Fourth Generation (4G) LTE makes use of MIMO technology (which requires multiple RF chains) to achieve significantly higher data rates. Previous generation 2G and 3G DAS technology with a single radio chain generally cannot support MIMO deployment without a significant upgrade of the system. Distributed antenna systems, due to all the expensive cabling and RF hardware required, are very expensive to install, and many operators and venues are trying to figure out how to deploy 4G LTE indoor solutions without a DAS.

This paper presents the first live network measurements, in a stadium environment, of a new technology which has been given the name "OneCell" that represents a hybrid combining many of the advantages of both conventional DAS technology and modern "Cloud RAN" based smallcell technology. The "OneCell" architecture is a practical implementation of the "Virtual Cell" or "Cloud RAN" concept described in the literature [8]. In the "OneCell" architecture, the LTE eNodeB functionality is split between a centralized baseband controller (BC) and a distributed network of smallcell radio points (RP's). The radio points are connected and communicate via cat-5 Ethernet, using standard IP protocols, in a star configuration to the controller. The cluster of radio points forms one single LTE distributed eNodeB cell with up to 32 radio points and thus has no intercell borders associated with conventional standalone smallcell networks. The individual radio points rebroadcast the signals from the baseband controller or can actually reuse individual LTE subcarriers to provide additional capacity if there is enough isolation between radio points. The front-haul interconnect uses ordinary cat-5 Ethernet and standard IP protocols and commercial Ethernet Switches, as opposed to more expensive RF coaxial cable or fiber and associated hardware; thus, the deployed network has the advantages of a single cell in terms of interference and signaling combined with the cost structure associated with smallcells and enterprise-type Wi-Fi deployments. Figures 1a and 1b show simulated signal-

Manuscript received January 6, 2016. This work is a joint effort of University of Massachusetts Lowell ECE, Airvana now part of Commscope, and Nex-Tech Wireless.

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to-noise ratio for a single large cell made up of distributed radio points as compared to a cluster of standalone LTE small cells.

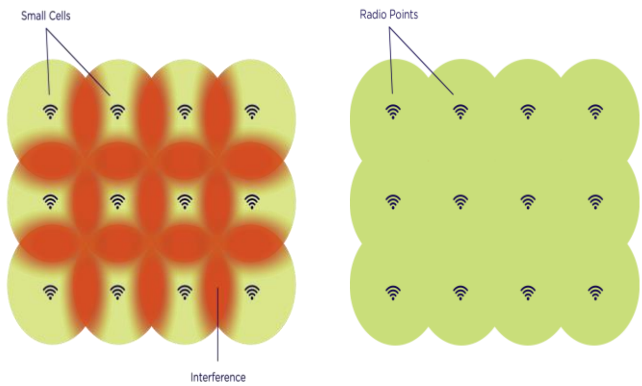

Fig. 1a and 1b Comparison of the Signal-to-noise Ratio of Conventional Smallcells and OneCell Technology Creating a Single Large Cell.

The general architecture of the deployment of the "OneCell" technology is shown in Figure 2. The Ethernet switches are used to provide power over Ethernet (POE) and to multiplex the signals to the Baseband Controller.

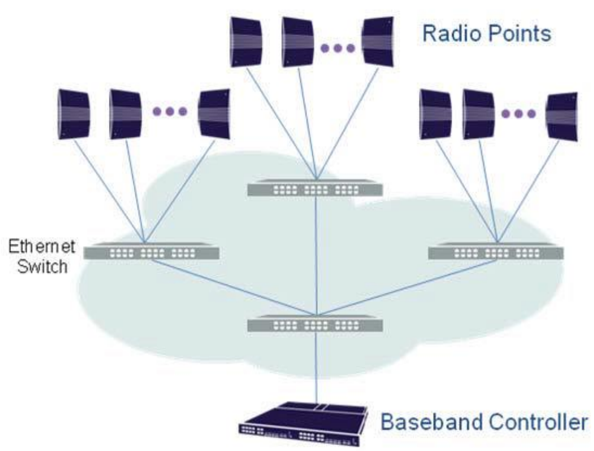

Fig 2. Architecture of the "OneCell" Cloud-Ran Smallcell System

II. First Deployment of a Cloud-RAN Smallcell Cluster in a Large Venue

To validate that the new "OneCell" technology can be used to provide LTE coverage in a large stadium venue currently without indoor LTE coverage, regional wireless operator Nex-Tech Wireless in Hays Kansas agreed to deploy and test the new technology in a medium-sized indoor arena at Fort Hays State University in Hays Kansas. The arena is approximately 90,000 square feet (8400 square meters) and seats about 7500 people when configured for graduation or concerts. It has two primary levels consisting of the main bowl with floor seating, fold-out bleachers, and a running track and concession areas located behind the main seating area. The second level consists of seating and a concourse with concession areas located behind it. Two carriers were deployed on Nex-Tech Wireless' LTE frequencies at 700 MHz (10 MHz LTE channel), and 1900 MHz (10 MHz LTE channel). Each baseband controller can support up to 256 simultaneous RRC connected users. Load balancing splits the users between the two carriers for improved user experience. The 1900 MHz system consists of 15 radio points (RP) covering the arena complex plus the training and office areas located in a 25,000 square foot (2300 square meters) building adjacent to the arena. The 700 MHz wireless network consists of 11 radio points covering only the stadium area. The main bowl and seating areas are covered by 4 ceiling-mounted radio points with overlapping coverage. Three radio points are used to cover the second level concession area and concourse, and four radio points are used to cover the entrances and the running track area. On the average, each radio point covers around 8000 square feet (750 m^2), with overlap designed in for redundancy. Each radio point operates at approximately 23 dBm out power per antenna (2x2 MIMO) into internal omni-azimuthal patch antennas. The radio points are the approximate size of a commercial Wi-Fi access point. There was minimal LTE coverage inside the arena from the macrocell network with the nearest LTE macrocell base station operating on 1900 MHz located approximately 600 meters from the arena.

Figures 3a and 3b show predictions of Signal-to-Noise-plus-Interference Ratio (SINR) in dB, for conventional and clustered smallcell technology for level 2 (balcony and back concourse) of the arena at 1900 MHz. This level is covered by 3 of the 15 smallcell radio points in the total design shown on the figures. The locations of the radio points are indicated by the small dots in the upper center, lower left and lower right corners of the figures. Predictions were performed using the industry standard IBWave modeling tool, with the dominant path propagation model [3]. Figure 3a, which plots SINR in the second level, shows that there is uniform high-quality coverage in terms of SINR from the Cloud-RAN based single cell solution, since there are no intercell borders as compared to Figure 3b which shows conventional standalone smallcells. In the figures the colored scale is the same. Figures 3c and 3d plot predictions of the SINR for the main bowl area for the Cloud-Ran solution and conventional small cells respectively. The radio points are located in the corners of the arena.

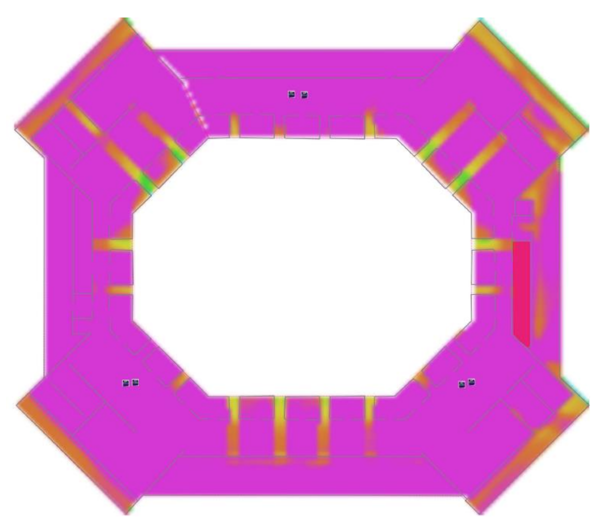

Fig 3a SINR Prediction for Level 2 for the "OneCell" Cloud-Ran based single virtual cell

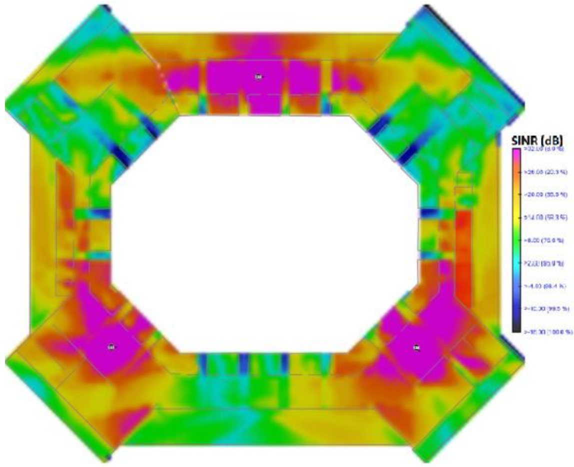

Fig 3b SINR Prediction for Level 2 for Standalone Cluster of LTE Smallcells

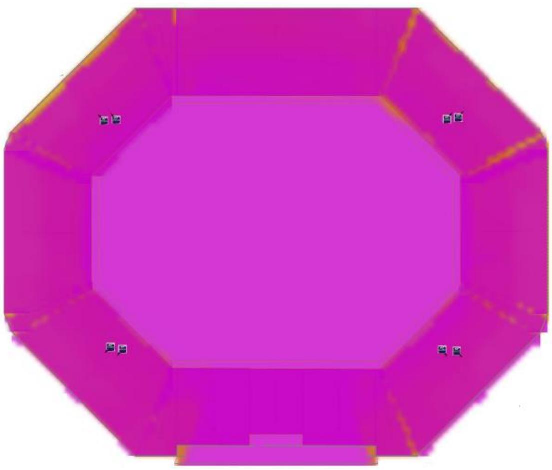

Fig 3c SINR Prediction for main bowl for the "OneCell" Cloud-Ran based single virtual cell

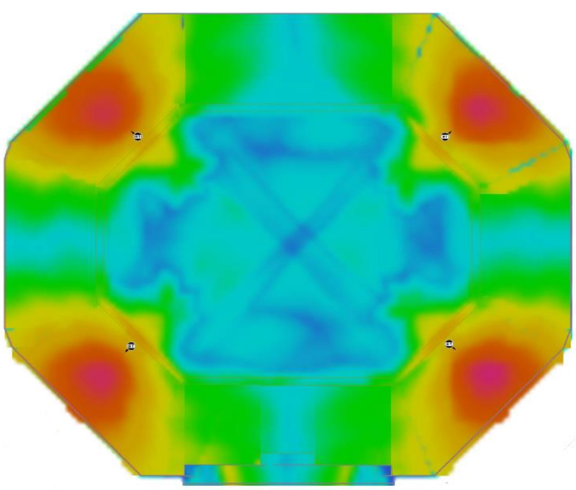

Fig 3b SINR Prediction for main bowl Standalone Cluster of LTE Smallcells

III. MEASURING SMALLCELL COVERAGE QUALITY IN A STADIUM VENUE

Mapping coverage in a large venue is very challenging both from a peoplepower and cost view. The conventional method for mapping indoor coverage measurements [4, 5] is to create a series of waypoints on a building map. As a human tester walks a linear path from waypoint to waypoint, the tester enters the waypoints into the logging system. The measurements are then positioned along the line connecting the waypoints using linear interpolation. This measurement process is time consuming and labor intensive, and it is hard to reproduce path conditions from test to test. It is also hard to create more complicated or involved coverage mapping routes in a venue such as the arena because interpolation between waypoints requires many waypoints when mapping non-linear paths. To create a system that provides a significant improvement in terms of both accuracy and repeatability over manual measurement techniques, we designed an autonomous robotic coverage mapping system that can automatically create its own maps and localize its position in a venue with an accuracy of 1 foot. The robotic system described in greater detail in [7] is shown in Figure 4 sitting on the basketball floor of the arena. It is equipped with a calibrated commercial handset (UE) and purpose-built data logging system that communicates with the position location system in the robot and the handset. Post-processing software allows for creating calibrated coverage maps for different LTE parameters.

Fig. 4. Robotic Autonomous Coverage Measurement Platform

The robotic coverage characterization system was used at the approximately 90,000 square foot (8400 square meter) arena to map primary LTE coverage quality parameters: Received Signal Reference Power (RSRP, in dBm) is a measure of received signal strength calculated as the average received power measured in the reference channels. RSRP is independent of load and is therefore a standard measure of RF signal coverage. Signal to noise plus interference ratio (SINR, in dB) is a measure of the quality of the signal, not just its intensity because it measures both the background noise and interference levels. Channel quality indicator (CQI) is a number between 0 and 15 that is related to the signal to noise plus interference ratio and influences the modulation and coding (MCS) transmitted and therefore determines the effective throughput. Figures 5 (a, b and c) show the measurements of RSRP, SINR, and CQI as the robot went through each seating area entrance on level 2 and then mapped the coverage along the edge of the upper seating level. Figures 5 (d, e, and f) show the same measurements on the main floor area. The figures show not only the uniformity of the signal strength as measured by RSRP, but the overall uniformity of the coverage quality as measured by SINR and CQI. A small amount of co-channel macrocell interference is observed at 1900 MHz due to the macrocell located about 600 meters from the arena. Very little signal from the macro leaks in due to the construction materials used in the structure.

Another way to analyze the data is to compute cumulative distributions of RSRP, SINR and CQI over the entire path traversed over the multiple-hour measurement intervals. This analysis provides an indication of the overall signal quality as experienced by random users throughout the arena. Figures 6 (a,b,c) plot cumulative distributions of the three metrics (RSRP,SINR and CQI) to show the overall uniformity and quality of the measured coverage. In these plots 90% of the locations mapped by the robot had better than 25 dB Signal-to-Noise-Plus-Interference Ratio and close to 99% had better than 20 dB SINR. Over 90% of the locations had a CQI of 12 or better which corresponds to providing approximately 45 MBPS or better instantaneous data rates (in 10 MHz bandwidth) to

90% of the locations in level 2, and 25MBPS or better to 99% of the locations mapped.

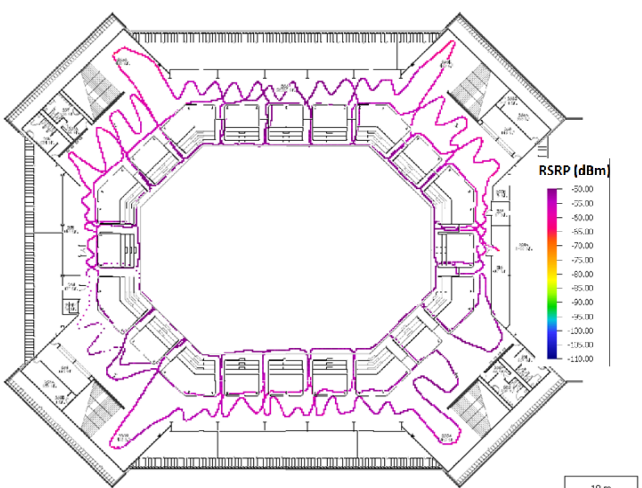

Figure 5a Map of Measured RSRP Coverage on Level 2 Seating and Concession Areas.

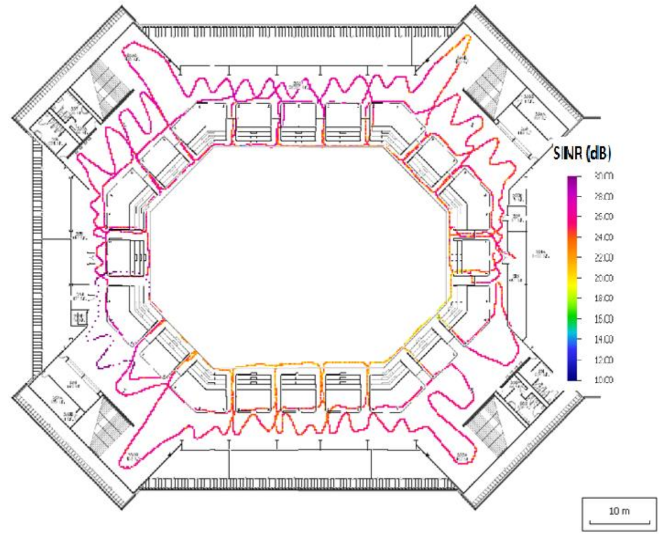

Figure 5b Map of Measured SINR Coverage on Level 2 Seating and Concession Areas.

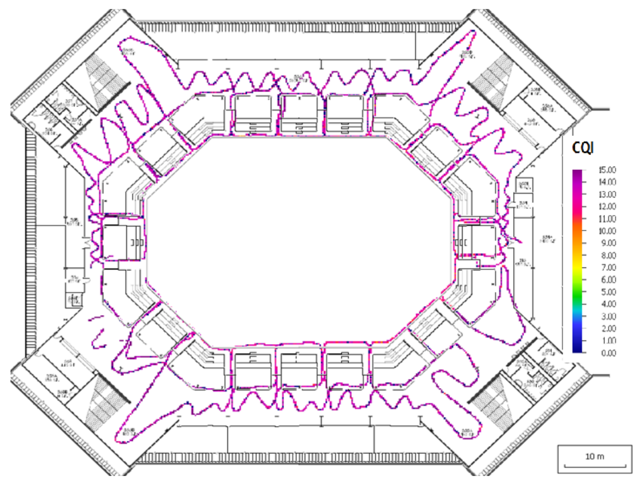

Figure 5c Map of Measured CQI Coverage on Level 2 Seating and Concession Areas.

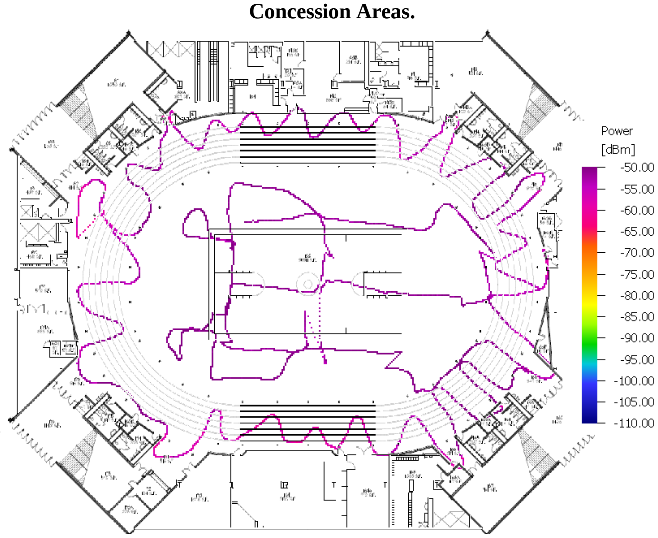

Figure 5d Map of Measured RSRP Coverage Main Level.

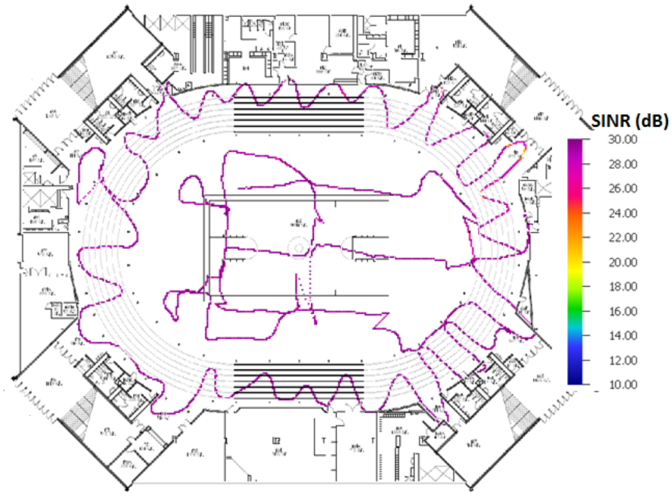

Figure 5e Map of Measured SINR Coverage in Main Level.

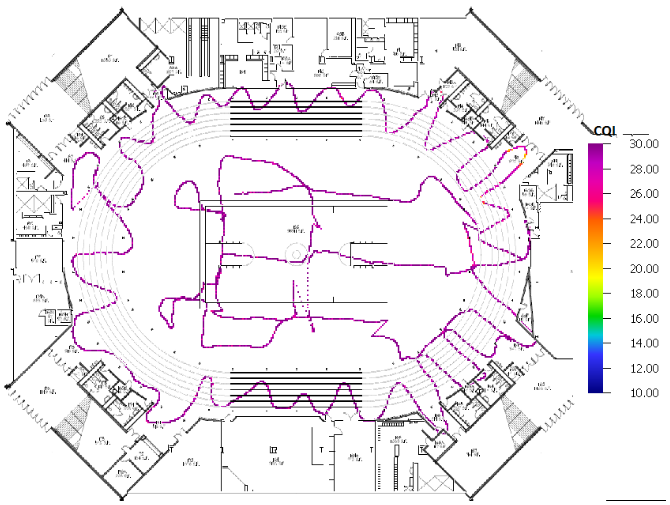

Figure 5f Map of Measured CQI Coverage on Main Level.

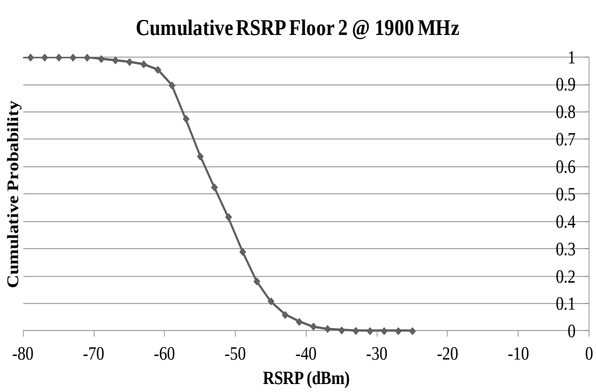

Fig 6a. Cumulative Distribution of RSRP for 2nd Level and Concession Area.

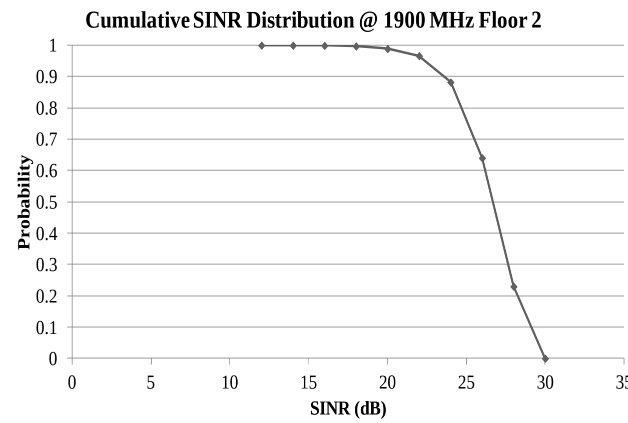

Fig 6b. Cumulative Distribution of SINR for 2nd Level and Concession Area.

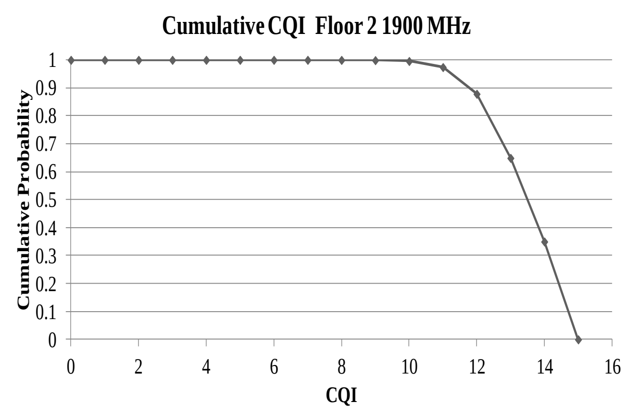

Fig 6c. Cumulative Distribution of CQI for 2nd Level and Concession Area.

IV. Conclusions

The use of conventional smallcells in a large venue has been previously considered to be an oxymoron due to relatively small coverage area, intercell borders, and frequent handout between individual smallcells. The cloud-RAN coordinated smallcell technology described in this paper provides coverage quality comparable to a conventional DAS with the cost structure of smallcells or enterprise Wi-Fi. Several large events held at the arena resulted in large crowds that tested the system. At peak usage, systems were processing in excess of 22,000 connections per hour with over 90 simultaneous RRC connected users. Measurements made throughout the arena during events were consistent with predictions and demonstrated the uniformity and high quality of the coverage in terms of SINR and CQI relative to a cluster of standalone smallcells. The system had adequate capacity and key performance metrics (KPI's) were consistent with macrocellular and DAS performance. Individual data rates in excess of 60-65 MBPS on the 10 MHz channel were experienced by users due to the lack of interference from multiple cells. The average CQI experienced by all users as measured by the system was 12.8, which is considered to be excellent coverage quality.

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