5G CrowdCell with mm-Wave SDR Based Backhaul

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Abstract. This paper presents the 5G CrowdCell platform developed by Lime Microsystems, as well as future mm-Wave SDR platforms which are under development, and which, among other applications, will be used as the CrowdCell backhaul.

Keywords: 5G · CrowdCell · mm-Wave · SDR · Open source

1 CrowdCell Platform

1.1 CrowdCell

CrowdCell concept was introduced by Vodafone [1]. In short, this concept presents the open source cellular relay platform using general purpose processors (GPP) and software-defined radio (SDR) technologies.

In more details, CrowdCell presents a relay concept, whereby an intermediate "Crowd" enabled device relays traffic between a customer UE and the macro network. Its main benefit is to be a rapid and low cost small cell solution thanks to its Plug-and-Play (P&P) concept by means of using the available 4G coverage.

The concept is also promoted through the CrowdCell Project Group within the Telecom Infra Project (TIP) [2]. The CrowdCell Project Group focus is on creating a CrowdCell by leveraging General Purpose Processing (GPP) platforms, Software-Defined Radios (SDR) and Open Source designs for both hardware and software to minimize costs with a "one design" flexible platform.

Even if CrowdCell delivers fraction of capacity compared to standard small cell, this concept is expected to be widely accepted since CrowdCell cost of ownership is dramatically reduced, because it is detached from physical location. Additionally, as a result of openness of the concept and utilization of GPP, the CrowdCell software is expected to be able to run on any platform (such as Raspberry Pi, standard PC, etc.).

1.2 Lime Microsystems CrowdCell Implementation

Lime Microsystems is at the forefront of CrowdCell implementation, and was named as a provider of end-to-end (E2E) technology for the CrowdCell at the TIP Summit 2018 [3].

A. Kliks et al. (Eds.): CrownCom 2019, LNICST 291, pp. 386–393, 2019.
https://doi.org/10.1007/978-3-030-25748-4_29

Lime Microsystems' CrowdCell platform was acknowledged as the most compliant E2E platform.

Fig. 1. Vodafone CrowdCell prototype developed by Lime Microsystems

Lime Microsystems' CrowdCell implementation (Fig. 1) is based on a standard PC, and LimeSDR, which is an open source, app-enabled SDR platform [5]. It was developed based on the LimeNET platform [5].

In terms of its narrow definition, a CrowdCell utilizes existing mobile network as a backhaul. However, acknowledging flexibility as one of the utmost priorities, other types of backhaul may be used for a CrowdCell platform in a broader sense. Depending on the availability, those could be, for example, an Ethernet connection, or even, preferably, high-performance flexible dynamic mm-wave backhaul (Fig. 2).

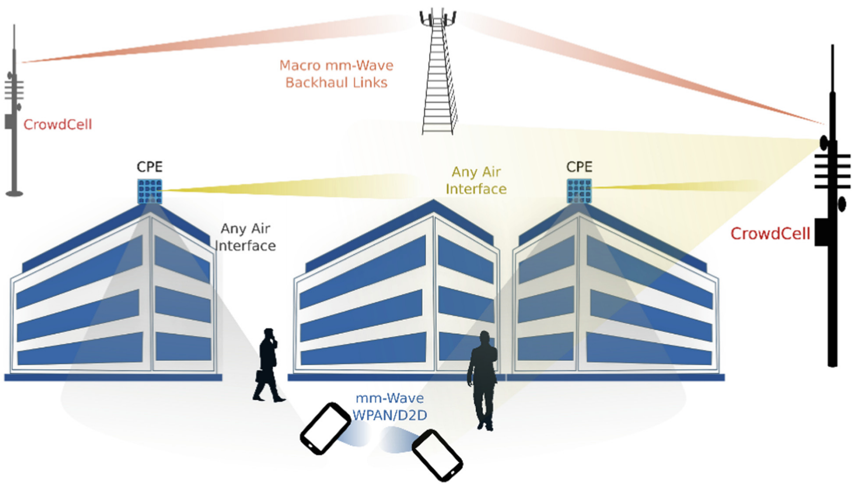


Fig. 2. CrowdCell with mm-Wave Backhaul

Lime Microsystems is developing mm-Wave SDR which will provide the base platform for such backhaul, among other applications. This platform is detailed in the following.

2 mm-Wave SDR Platform

Key enablers of the Lime Microsystem platforms are own integrated transceivers.

LMS7002M transceiver, which is Lime's second-generation field programmable RF (FPRF) transceiver IC, covers all the way from 100 kHz to 3.8 GHz, with 2 × 2 MIMO and extended functionality [7]. This IC provides the foundations for the LimeSDR platform family.

LMS8001 is a single chip up/down RF frequency shifter with continuous coverage up to 10 GHz, utilizing 4 highly flexible channels [8, 9]. This IC enables the Companion platform [10, 11].

With a goal of increasing continuous frequency coverage, the integrated transceiver roadmap extends to 100 GHz (Fig. 3).

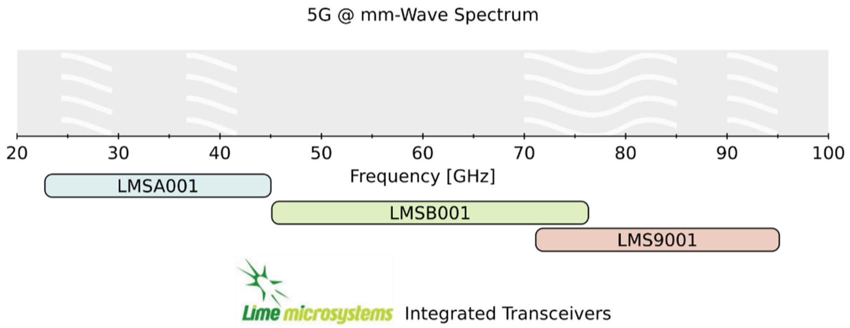


Fig. 3. Lime Microsystems' mm-Wave transceiver family (under development)

Lime Microsystems' mm-Wave integrated transceiver family targets the 5G, multi-gigabit fronthaul/backhaul, and SDR applications.

Millimeter waves are crucial for boosting the capacity in 5G (Fig. 4).

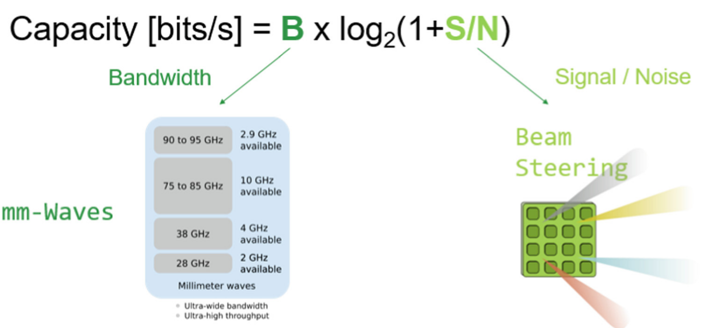


Fig. 4. Millimeter waves enable boosting capacity in 5G

The task of determining optimal architecture, interface, technology, beamforming architecture, is not trivial and is application specific [12].

Zero-IF architecture is chosen, with IQ baseband signals determined as an optimal interface between the mm-wave radio, and readily available baseband processing platforms.

SiGe Bi-CMOS was determined as an optimal technology for mm-wave ICs. Technology break-down of the complete analog-beamformer platform is illustrated in Fig. 5. Millimeter wave radio implemented in Bi-CMOS is connected to the commercially available CMOS baseband. Conceptually, the implementation is illustrated in Fig. 6. This architecture will generally be suitable for UE and CPE applications. In case higher power is required, as with BTS applications, GaN or III-V semiconductor front end can be added.

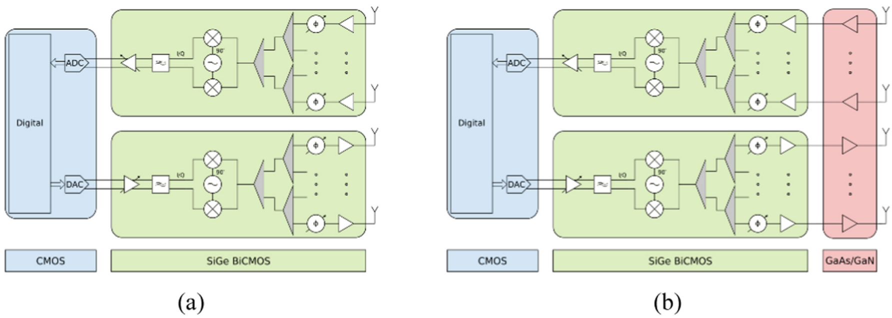


Fig. 5. Millimeter wave platforms technology break-down

Separate TX and RX chips are targeted. Primarily, 4 beam-steering channels per chip are targeted. Scaling the number of channels will be straight-forward in future designs, if required.

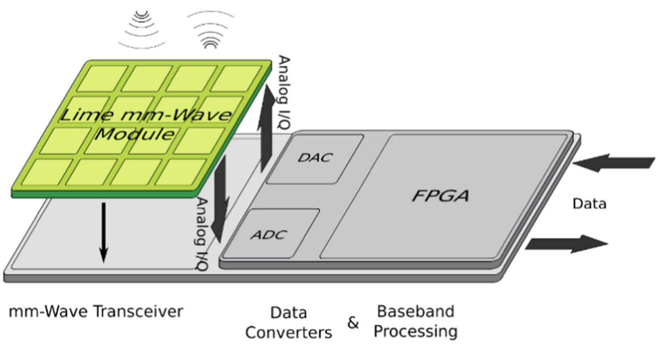
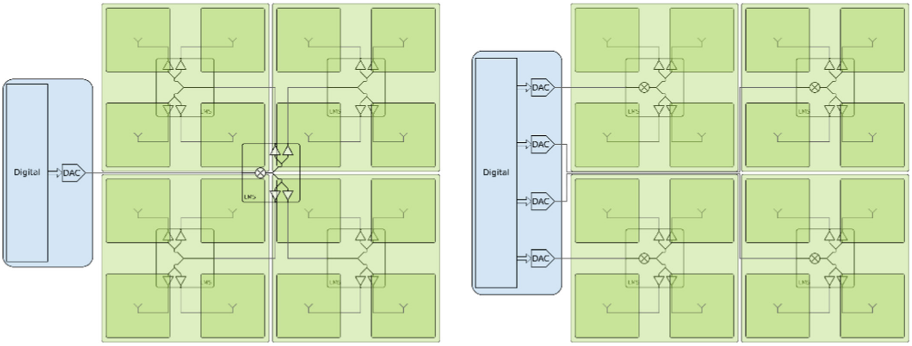


Fig. 6. Lime mm-Wave module & main board concept

The key to flexibility of the millimeter wave systems is modularity. Namely, number of the phased array elements, as well as the beamforming architecture should be flexible in order to meet requirements of various applications and scenarios (Fig. 7).

Each of the Lime Microsystems' mm-Wave chips includes frequency conversion. However, by simple modification of a single metal mask, baseband and mixer can be bypassed. Such a chip could be used to increase the number of channels in purely analog beamforming portions of the systems.



(a) Analog Beamforming (b) Hybrid Beamforming

Fig. 7. mm-Wave platforms flexibility, modularity & scalability

Architectures of the RX and TX chips are presented in Figs. 8 and 9, respectively.

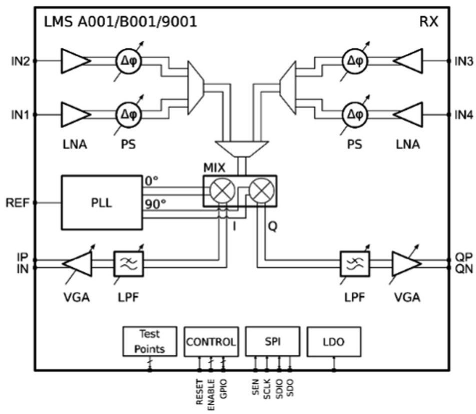


Fig. 8. RX chip architecture

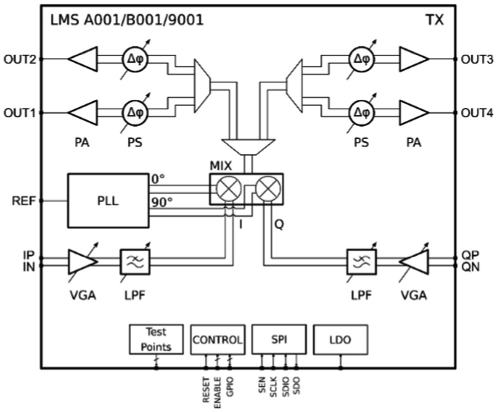


Fig. 9. TX chip architecture

Receiver chain starts with the low noise amplifier (LNA). In order to reduce the number of pins, the LNA input is single-ended, followed by the integrated balun. LNA is implemented as differential, two-stage cascode, providing the trade-off between robustness, bandwidth, gain and noise.

Phase-shifters are implemented as 5-bit vector modulators. Quadrature signal is generated by the Quadrature All-Pass Filter (QAF), and followed by the quadrature Variable Gain Amplifiers (VGA).

Power combiner is implemented as two-stage differential Wilkinson divider.

Signal combined from all channels is fed into a quadrature down-conversion mixer.

Baseband blocks (I and Q) are following the mixer. They consist of 8-steps digitally controllable low-pass filter, with 1 GHz maximum bandwidth, and the variable gain chain. Fast AGC and DC offset cancellation are implemented within the baseband block.

Frequency synthesizer is a fractional-N PLL with multiple fundamental frequency VCO cores. Loop filter is 3rd order with programmable component values integrated on chip. Quadrature is generated by the multistage Poly Phase Filter (PPF).

Power amplifier provides high linearity output signal over the complete band, and provides single-ended output, reducing the pin count.

The TX and RX chips targeting the 71–95 GHz range (LMS9001) are in the top-layout design phase.

In order to avoid grating lobes in a phased array, distance between antenna elements is usually chosen to be equal to the half of the wavelength (λ/2). To facilitate efficient module design, channel inputs/outputs of the chips are targeted to be equally spaced at the λ/2 of the central frequency. In addition, chip size must be smaller than module with 2 by 2 integrated antennas, which is generally λ by λ, which imposes harsh area constraints. Hence, careful top level design is necessary.

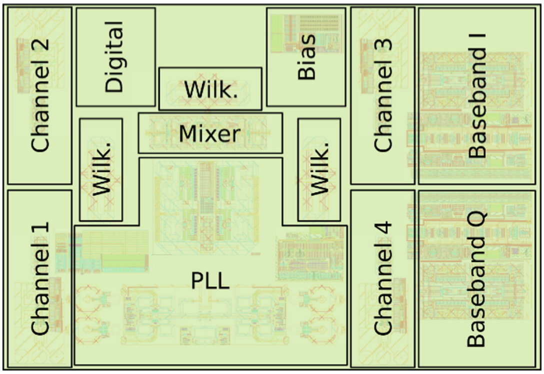


Fig. 10. LMS9001 RX chip top layout (approx. 3 × 2 mm)

Top layout of the LMS9001 RX chip with denoted block is presented in Fig. 10. Top layout of the TX chip is similar.

Depending on the target application, different packaging options are considered (Fig. 11). Module with antennas would enable easy, cheap multi-element modular solutions. BGA package would be appropriate for applications where high-performance antennas and/or high-performance external amplifiers are required. Advanced packaging technologies as eWLB (embedded Wafer Level BGA) will also be considered.

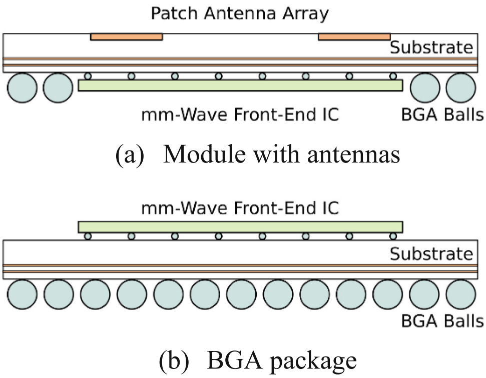


Fig. 11. Lime mm-Wave packaging options

3 MyriadRF

Lime Microsystems is committed to open source and in 2012 founded the MyriadRF open source initiative [13], a multi-stakeholder community and an umbrella for open source hardware (OSHW) and free and open source software (FOSS) wireless, RF and related projects. Over the years MyriadRF has grown to become a vibrant community with hundreds of active members and projects spanning amateur radio, radioastronomy, test & measurement, cellular networks, and satellite communications.

All LimeSDR hardware designs are published via MyriadRF under open source licences, together with associated FPGA gateware and microcontroller firmware, plus supporting host driver software and utilities. This includes hardware designs that range from the low cost SISO LimeSDR Mini USB peripheral [14], to the high performance 4×4 MIMO LimeSDR QPCIe [15]. In addition to which Lime Microsystems have open sourced their adaptive digital pre-distortion implementation for power amplifier linearisation, LimeADPD [16], which is targeted to the LimeSDR QPCIe.

Lime Microsystems believes that the democratisation of innovation is key to the future of wireless communications and in addition to founding MyriadRF, has hosted numerous public workshops, provided free developer hardware, and provided significant support for community events such as Electromagnetic Field (EMF) Camp [17].

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