Portable Cell Initiative

Range and Subscriber Capability Analysis for Microcells

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**Summary**

The estimated range of a microcell, with an antenna that is 30 m from the ground and which is operating on the 900 MHz GSM frequency, is around 4 km and may server an estimated 3340 subscribers in the surrounding area when utilizing the recommended hardware.

**Range Analysis**

To find the range of the base station to subscribing users, one must calculate how the radio signals propagate between the base station antenna and the mobile device. There are two connections during cellular service, a downlink and an uplink. In each case, the radio transmission (either from the base station to the mobile device or vice versa) must be strong enough to overcome the background electromagnetic radiation, known as “noise”. These transmitted power quantities will determine the range of the microcell.

The fundamental way to determine the range of an antenna is for the radio transmitter to transmit at a high enough power, PT, to overcome the free space propagation loss and noise that is fundamental to the travel of electromagnetic waves from a source to the receiver.

The power transmitted by the base station antenna depends on both the software-defined radio and the amplifier. The bladeRF x40, the recommended SDR in this project, can generate +6 dBm of TX power[[1]](#footnote-1) and its amplifier can provide a maximum +31 dBm of amplification[[2]](#footnote-2). Together, the system provides +37 dBm of transmission power, equivalent to 5.01W.

The power transmitted by a GSM cell phone depends significantly on the model and the settings of the device, which adjust the power to optimize battery life. The GSM system controls the phone’s transmission power through signals sent by the base station to optimize the link from the mobile device back to the base station. This way, the mobile device will conserve battery life while overcoming the noise of the surrounding area. GSM900 standards dictates that the peak mobile TX power (Cellular Radio, 203)[[3]](#footnote-3) should be 20W (+43 dBm) at the Class 1 power setting (with incremental classes every 2 or 4 dBm). Since the GSM cell phone is capable of higher transmission power than the base station and the base station has a low noise amplifier that can boost signals up to 20 dB from the mobile device, PT will be considered at the base station transmission power of +37 dBm.

According to Cellular Radio (p.44), the equation for determining the power is by weighing the effects of the signal to noise ratio *S/N* required for the signal to be processed, the effective noise threshold NR, the free space propagation loss factor *L*, the gain from the transmitter (GT) and receiver (GR) due to amplification or antenna gain, and building penetration loss (BPL) from radio signals entering through structures to reach mobile devices. If these factors are considered, then any transmission power above this threshold allows radio communications:

If the power transmitted can overcome these factors, then successful GSM communications may be transmitted. In this equation, the receiver noise threshold is a measure of the ambient and spurious electromagnetic radiation that interferes with the radio signal. In this formula, the effective noise temperature is assumed to be around the reference temperature of 270K, which is near suburban noise levels at 900 MHz (Cellular Radio, 45). The equation also factors in the bandwidth which GSM occupies, which is 180 kHz per channel[[4]](#footnote-4):

Several of the inputs may vary in different environments, but here is a simulation of the mobile device receiving signals from the base station transmitter:

|  |  |  |
| --- | --- | --- |
| Variable | Value | Description |
| S/N | +9.5 dB | 9 dB is described as the worst-case baseband S/N ratio, and an implementation margin of 0.5 to 2 dB[[5]](#footnote-5) is typically added |
| NR | -121.4 dBm | From the above equation for receiver noise threshold in GSM systems |
| GT | +2.16 dB | Monopole antenna with a virtual ground will have a worst-case gain of approximately a dipole antenna. However, the maximum gain could be up to 6.48 dB\*. |
| GR | 0 dB | Assume that the cell phone antenna is omnidirectional and isotropic |
| BPL | 10 dB | Conservative estimate: BPL ranges from 10-20 dB (Cellular Radio, 56) |

Table 1: Values for the PT required for base station communication (downlink) with a mobile station

\*See antenna analysis for this estimate and other considerations that may affect this value

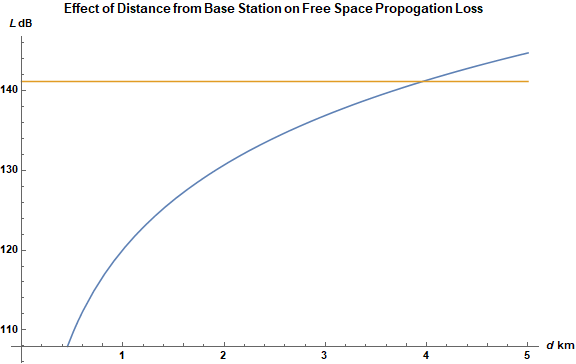
Now that the Lmax has been determined as the most the radio signal may fade before transmission no longer functions, relationships may be calculated between the free space propagation loss *L* and distance *d* between the source and receiver and the wavelength of the radio wave (Cellular Radio, p.44)

However, interference occurs due terrain and obstacles between the transmitter and receiver because radio waves reflect off these surfaces and occasionally combine to cancel out the signal. These multipath interferences can have been experimentally modeled for different urban and suburban environments by Okumara in 1986 and formulated by Hata in 1980[[6]](#footnote-6). This equation provides the free space propagation loss factor and is based on urban area losses in medium and small cities from ground reflections, buildings, and elevation changes (Mobile Communications, p.25):

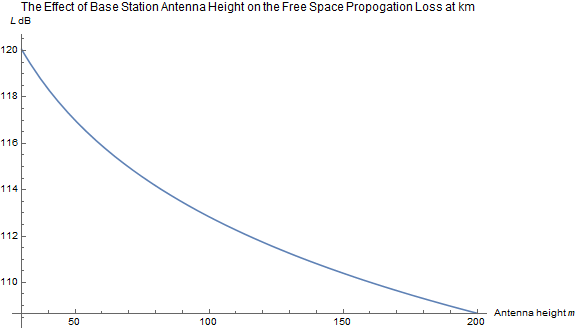
Where *fc* is the frequency between 150 and 1500 MHz, *hb* is the height of the base station antenna between 30 and 200 m, *hm* is the height of the mobile antenna (how high the cell phone is from the ground) between 1 and 10 m, and *R* is the distance between base station and antenna between 1 and 20 km. In this simulation, these variables were used:

|  |  |
| --- | --- |
| Frequency | 900 MHz |
| Height of mobile antenna | 1 m |
| Height of base station antenna | 30 m |

Table 2: Parameters of the range analysis calculations



Additionally, an operator of a microcell might want a higher antenna height, if possible, to improve the signal and increase Rmax. The following graph shows this relationship as the free space propagation loss at 1 km distance from the cell, assuming the same 1 m mobile antenna height and 900 MHz frequency as before:



|  |  |
| --- | --- |
| Antenna Height (m) | Maximum Range (km) |
| 30 | 3.96 |
| 40 | 4.59 |
| 50 | 5.17 |
| 60 | 5.73 |
| 70 | 6.25 |
| 80 | 6.76 |
| 90 | 7.26 |
| 100 | 7.74 |

Table 3: Maximum cell range based on antenna height for reference

**Subscriber Capacity**

To calculate how many subscribing mobile devices a cell may support, one may use the general equation (Cellular radio, 254):

The number of channels available for a GSM system is heavily dependent on the version and frequency utilized, and may be dynamic based on these factors. The GSM system recommended for worldwide compatibility is centered on the 900 MHz band, but other bands may be utilized to reduce congestion from nearby cell towers. Lower frequencies also “improve coverage with lower power”[[7]](#footnote-7) The band is divided into radio “carriers” or channels used for communications, which range from 925 to 960 MHz for downlink and 880 to 915 MHz for uplink (Cellular radio, 191). Within these ranges, there is a maximum of 125 channels (CR, 191), which allow 8 slots per channel per the TDMA technology[[8]](#footnote-8). Overall, a GSM system can support up to 1000 voice channels if needed (Tipper).

The number of actual channels utilized heavily depends on the computing power of the Linux server that is processing information. The largest bottlenecks for GSM processing include the throughput of the USB connection between the software-defined radio and the Linux server and the processing power of the Linux server. Major in CPUs and new USB3.0 standards have greatly decreased the costs and complexity of equipment required to support GSM communications. Based on previous research of the computing requirements[[9]](#footnote-9), the following performance statistics are estimated, but must be experimentally verified:

|  |  |
| --- | --- |
| SpecFP92 metric/logical channel (Turletti, Tennenhouse) | 30 (min) to 51 (max) |
| Computing power required per logical channel (MWIPS) | 36.3 (min) to 61.7 (max) |
| Raspberry Pi 3.0 B computing performance (MWIPS) | 1113 |
| Odroid-XU4 computing performance (MWIPS) | 6186.3 |
| GSM maximum throughput per channel | 284.33 kbps |
| USB2.0 throughout performance\* | 26.2 MB/second |
| USB3.0 throughoutput performance\* | 258 MB/second |
| Raspberry Pi 3.0 B channel support\*\* | 18 |
| Odroid-XU4 channel support\*\* | 100 |

Table 4: Performance requirements for GSM based on Linux server options. Computing power per channel is based on the SpecFP92 benchmark and server hardware is tested with Whetstone double precision benchmark (x3)[[10]](#footnote-10).

\*Measure on the Odroid-XU4 Linux server which was connected to an SSD (write speed results displayed which are similar, but slower to read speeds)

\*\*Theoretical values that have not been tested in deployed environments with interference

The connection between the radio and Linux server does not represent a bottleneck for GSM data, as even with each channel transmitting 284.33 Kbps of throughput, USB2.0 has the capability of supporting up to 738 voice channels if required. USB3.0, which is recommended, can support nearly 10 times the channel data throughput, which is well above the 1000 voice channel capacity.

The main bottleneck is instead, the processing power (which is measured in how many floating-point operations each Linux server can complete per second). The results are shown in Table 3 based on the computing power bottleneck and the calculations are explained in the appendix. Overall, the recommended Linux server can handle 100 voice channels at once.

The “Subscriber Erlang rate” describes the amount of time each subscriber uses the network for calling or data operations. The unit of Erlang may be defined as the “average number of calls in progress simultaneously during the period of one hour” (Cellular Radio, 251). The actual calling rate of subscribers is typically six calls a day of 150 second duration (Cellular Radio, 253). To calculate this, use the equation on p.253:

According to Cellular Radio, the most traffic will be concentrated in a “busy hour” (Cellular Radio, 253), where the calling rate increases to a maximum of 0.03 Erlangs. Now, assuming a grade of service of 0.01 (1/100 calls are delayed or blocked), the subscribers may be calculated (Cellular Radio, 254) with an Odroid-XU4 server as:

**Appendix:**

The calculations in table 1 to determine the computing power required per logical channel in MIPS was done by first ascertaining the SPECFP92 score required per logical channel:

SPECFP92 per logical channel = 30 (min) to 51 (max).

For the DEC 3000/900 AXP workstation, the same Turletti, Tennenhouse article states that the SPECFP92 performance is: 187.6.

The Whetstone performance in MWIPS (millions of whetstone instructions per second), but in double-precision mode of the DEC 3000/900, is 227[[11]](#footnote-11).

Therefore, each logical channel Whetstone score in MWIPS = 36.3 (min) to 61.7 (max)

From the Whetstone (x3) double precision benchmark run by Hardkernel, the raspberry pi 3 has a score of 1113 MWIPS and the Odroid-XU4 has a score of 6186.3

The number of channels supported by each Linux server can therefore be determined by dividing the Whetstone performance of each server device by the maximum (worst-case scenario) amount of computing power in MWIPS to operate each voice/logical channel.

Note that both the whetstone and SPECFP92 benchmarks measure the amount of floating-point operations that the computer can handle and are therefore open to correlation.

Each logical channel is a voice channel (a radio carrier is a 200 kHz band that allows data to be sent in “bursts” via time division multiple access, which allows 8 users to have logical, or voice channels per radio carrier)

1. https://www.nuand.com/blog/product/bladerf-x40/ [↑](#footnote-ref-1)
2. https://www.nuand.com/blog/product/amplifier/ [↑](#footnote-ref-2)
3. Macario, R. C. (1997). Cellular radio: principles and design (2nd ed.). New York: McGraw-Hill, 44. [↑](#footnote-ref-3)
4. http://inf-server.inf.uth.gr/courses/CE433/tutorials/GSM%20Transceiver.pdf and http://mobiledevdesign.com/learning-resources/introduction-gsm-and-gsm-mobile-rf-transceiver-derivation [↑](#footnote-ref-4)
5. http://mobiledevdesign.com/learning-resources/introduction-gsm-and-gsm-mobile-rf-transceiver-derivation [↑](#footnote-ref-5)
6. Sasaoka, H. (2000). Mobile Communications. Tokyo: Ohmsha, 25. [↑](#footnote-ref-6)
7. Iedema, M. (2015). Getting started with OpenBTS: build open source mobile networks (1st ed.). Sebastopol, CA: OReilly. [↑](#footnote-ref-7)
8. Tipper, D. (n.d.). Global System for Mobile. Lecture presented at Telecom 2720 in University of Pittsburg. Retrieved from http://www.pitt.edu/~dtipper/2720/2720\_Slides8.pdf [↑](#footnote-ref-8)
9. Turletti, T., & Tennenhouse, D. (1997). Estimating the computational requirements of a software GSM base station. Proceedings of ICC97 - International Conference on Communications. doi:10.1109/icc.1997.605186 [↑](#footnote-ref-9)
10. http://www.hardkernel.com/main/products/prdt\_info.php [↑](#footnote-ref-10)
11. http://www.roylongbottom.org.uk/whetstone.htm [↑](#footnote-ref-11)