AirGSM: An Unmanned, Flying GSM Cellular Base Station for Flexible Field Communications

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Abstract—**We present a functional implementation of a lightweight GSM (Global System for Mobile Communications) cellular base station and core network based on open-source software, coupled with a simple and rapidly deployable autonomous aerial vehicle for establishing field communications in the absence of commercial service. We advocate the utility of mobile GSM cellular devices for communication and data acquisition in many types of fieldwork, posing advantages in functionality over conventional long-range push-to-talk radios and advantages in size over laptop type data terminals. We argue that alternative radio communications technologies inevitably fail to simultaneously optimize cost, power management, range, integration, and spectral efficiency compared to the GSM radio interface.**

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1. INTRODUCTION

GSM cellular radio standard offers a nearly ubiquitous interface to portable communications devices, and possesses favorable radio characteristics: low channel bandwidth, high inherent resiliency to errors through both radio design and channel coding, mature and stable implementation in handsets, as well as impeccable system-level power efficiency.

As such, the advantages of leveraging a ubiquity of inexpensive and highly-integrated handsets, terminals, embedded modules and broadband interface adapters for all types of field communications are numerous. However, in many practical deployment scenarios, the abilities of these mobile terminals are crippled in the absence of commercial network coverage.

Our work seeks to restore network service to these field devices by presenting our own GSM infrastructure network to our field devices, whereby the network functionality of the mobile terminals is restored via our private GSM network in the absence of a commercial carrier. Our implementation focuses on transparency to the end user of the communications device and providing these services with the minimal set of resources required. We implement and present a low-footprint, self-contained GSM network combined with an autonomous aerial vehicle to provide data, SMS and voice communications services over a large physical area.

Figure 1. The AirGSM system attached to eight-rotor helicopter platform. The flight control systems can be seen above the rotor plane; the GSM radio system is shown below the rotor plane.

We briefly discuss our aerial platform, and further discuss the practical implementation of the cellular network components. We present the challenges associated with GSM network deployment and the practical and immediate challenges associated with aerial deployment. Furthermore, we discuss performance limitations of GSM and the improvements made by aerial deployment, and offer a comparison, discussion, and analysis to competing field

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communications solutions such as Wi-Fi and conventional terrestrial voice and data radios.

2. Related Work

Development of Cellular Technology

For decades, research in cellular communications has paved a foundation for resilient, flexible and efficient radio communications. Infrastructure vendors have pushed the limits of density and session management in an active network, handset research has yielded gains in system efficiency and integrated, compact designs, while standards bodies have successfully focused these industry efforts to install these improvements in a common architecture.[7][20]

While the majority of the core radio link principles of the GSM standard has remained largely unchanged for basic voice and short message services since the original draft of the standard, improvements in implementation and architecture of the system components has driven new efficiencies and flexibility seen in real system deployments. Aside from amendments to the standard for offering add-on services built on the original radio link specifications and improvements to the radio link standard for offering higher data rates and more flexible mobility management (as seen in the EDGE, UMTS and later LTE evolutions of the standard), research work on the GSM infrastructure has generally been focused in two directions: improvements to radio design technology to extend the link margins of GSM radio connections (largely without changes to the link specification), and improvements to the architecture of core network components driving down requirements for power and space.[17]

While early generation devices successfully implemented voice communications and later SMS (short message services) using a robust radio link standard, these devices were built on early technologies which were both loosely integrated and of insensitive radio design principles. While the resulting products functioned, shortcomings in the performance of the electronics required concessions to be made in practical network deployments. These concessions most often required the use of excess radio transmission power to close the radio link, and as a byproduct, imposed a higher noise floor in a cellular installation with unfavorable consequences to radio frequency resource management. [4]

To mitigate the drawbacks of these early generation devices, research has focused on improving the efficiency of the radio link while still adhering to the original protocol specifications of the radio interface. Gains to this effort are largely focused on better performing and more integrated radio design philosophies, as well as improvements in and commitments to using specialized integrated semiconductor radio designs, which offer intrinsic opportunities for greater resilience to contamination from noise.[2][14]

The progress of these efforts can be tracked in the improvements in deployment density and performance of commercial GSM installations. A review of previous work demonstrates the improvements to network infrastructure deployments. [1][5] As a result, reduced power usage and increased link margins were possible, allowing opportunities for increases in capacity and a reduction of spectrum resources. [3][4]

These improvements in integration can be seen in the consolidation of components and a resulting performance improvement in handset integration. [8][9] Systems on chip integration technologies, and efforts to hybridize components for radio integration are strongly attributed to performance enhancements and reductions in cost. [10][11]

Continued research has transitioned the development of cellular hardware using exclusively software driven radio approaches, with entire radio and protocol stacks implemented in software and realized with commodity programmable hardware. [18] Further research into software controlled operational topologies has presented modifications to adapt commercially-produced hardware to operate exclusively on custom software back-ends, offering the benefits of commercially produced and integrated enterprise grade radio hardware with flexible and efficient software controls. [19]

Low-Cost Unmanned Autonomous Aerial Vehicles

Unmanned Aerial Vehicles (UAVs) have become increasingly common tools in the world of research, as traditional barriers such as cost associated with them have greatly depreciated over the past decade. Inexpensive, lightweight and easily deployable, UAVs now provide a viable alternative to traditional forms of flight such as full-scale aircraft and helicopters. Additionally, the inclusion of a GPS radios, low cost MEMS sensors, system on chip designs allow autonomous control and management of flight functions. Robust wireless communication technologies with the on board flight control systems allow location referenced flight changes from the ground in real time.

The combination of these advances allow low cost aerial platforms to serve our needs in carrying a GSM base station to a predetermined altitude and will facilitate the desired radius of coverage. [21]

3. GSM Ecosystem

The GSM standard contains a collection of specifications nominating the services, functional components, and interfaces between all of the network elements required to implement and operate a commercial wireless telecommunications network. The written standard sufficiently describes every consideration required to implement any node in the GSM system topology conforming to the specification; however, deviations to the standard often exist in commercial equipment on some of the more internal interfaces. For the scope of this paper, we are concerned primarily with the properties of the radio link, as this is the only interface requiring fully compliant implementation to communicate with GSM handsets and modules. In addition to considering the radio link, we are concerned with the recommended component architecture and their functions in the network - even if only to eliminate components or consolidate their functionality.

Radio Properties: The Um Air Interface

All GSM radio links operate between the BTS (base transceiver station) and MS (mobile station) using a common protocol specification referred to as the Um link. The Um link is carried over a duplex channel pair using GMSK modulation (one bit per symbol) at a rate of 270.833 kHz on each of the duplex carriers. Transmissions are emitted in one of four standardized band pairs: 850 MHz, 900 MHz, 1800 MHz, and 1900 MHz. For each band, the GSM standard enumerates duplex channel pairs for both up-link and down-link carriers, a transmit and receive pair collectively known as a TRX (transceiver channel pair). Depending on the selections made by local regulatory authorities, one or more bands are generally reserved in a geographical area exclusively for licensed cellular services. Duplexing between the forward and reverse carrier channels is dependent on the band, and generally a function of the bandwidth allocated within a band: the lower bands, 850Mhz and 900Mhz, have 25Mhz and 35Mhz of allocated bandwidth with a channel duplex of 45Mhz; the upper bands, 1800Mhz and 1900Mhz, have 75Mhz and 60Mhz of allocated bandwidth with a channel duplex of 95Mhz and 80Mhz, respectively. Channel allocation within a band is standardized into absolute radio-frequency channel numbers (ARFCN), which are duplex paired with fixed spacing. Each sequential ARFCN is spaced 200 kHz from neighboring channels. [17][20]

Each physical carrier in both directions of the duplex link repeats a time-division multiplexed block framing sequence consisting of 1250 symbol periods, and is divided into eight equal time slots 156.25 symbol periods in length. Each time slot is capable of carrying the traffic of any number of logical channels, such that a single Um link is capable of carrying eight logical channel links at once across a duplex pair. Larger cellular site installations carry additional traffic by transmitting across several ARFCNs at once, and in so doing increasing the logical channels available for communications. When assigned to a physical channel, a logical channel carries small bursts of data in a revolving manner, filling the assigned timeslot during every subsequent rotation of the divided frame sequence. On the receiving end, data is collected from individual bursts and re-assembled into a contiguous data stream. Some logical channels use every sequential timeslot in an allocation, while others carry less traffic and utilize the channel resource in a sporadic or interleaved manner. [20][16]

The GSM standard enumerates multiple logical channel types to perform many of the tasks associated with network operations. While user payload-bearing logical channels take the form of simply named traffic channel (TCH) for voice or packet data channel (PDCH) for data, numerous housekeeping and initialization related logical channels exist to connect handsets and initiate communications sessions. These logical channels take two general forms: dedicated control channels (DCCH) and common control channels (CCCH). DCCH-type logical channels coordinate directed operations between the BTS and MS, such as delivery of SMS and initialization of call and data sessions. CCCH-type logical channels control operations between the BTS and all connected MSs, such as frequency offset correction, registration to the network, and paging. Any number of logical channel allocation schemes are allowed, enabling the network to add capacity for both traffic and management in a flexible manner, as there are few prescribed restrictions regarding logical channel allocation across physical carriers beyond meeting minimal sufficiency for management channel requirements. [16][20]

The smallest operable GSM network requires a single TRX on a radio channel pair conforming to the abilities of the radio hardware and the frequency resource allocation of the local authority. Through acceptable aggregations of logical management channels, all required CCCH and DCCH resources can be placed in a single time slot, allowing the reservation of the remaining seven slots for carrying user information, such as TCH voice and PDCH data channel allocations. [20]

Component Architecture

The GSM specification nominates a standard component architecture for a commercial GSM network. These components serve specific purposes to distribute the operation and control of a network, manage mobility between in-network users and roaming users, route information between users, and ensure the scalability of a deployed network. While all components are required for a functioning network, as each component performs a necessary function, smaller GSM installations may have minimal need for many components with few users, low traffic, and non-existent user mobility. Nevertheless, understanding these components is critical to enabling suitable modifications.

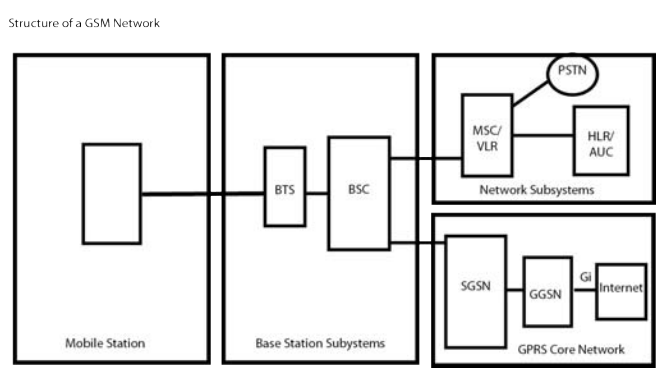

Figure 2. GSM Network Component Architecture.

MS - The mobile station (MS) is the portion of the network seen directly by the network users. MS devices take the form of handsets with a wide variety of features, embedded modules hidden in sensor equipment, or wide-area modems built into modern laptop computers. The MS is the principle gateway for a user to engage with network services. At a minimum, a MS communicates with a subscriber identity module card and with the network over the Um air interface. [20]

SIM - The subscriber identity module (SIM) is a small embedded computation device on a standard smart card. This micro-controller is responsible for providing the MS with identity information which can be used to uniquely register a MS on the network, as well as other encryption related services. [20]

BTS - The base transceiver station (BTS) is the radio front-end of a commercial GSM network installation. A collection of BTS nodes are distributed over a geographical area such that in an ideal installation, an MS can close a radio link to at least one BTS within a service area. The BTS presents the Um air interface to the MS, and the A-bis interface to the base station controller. [20]

BSC - The base station controller (BSC) is the local operations management for the radio resources presented by a BTS node or collection of BTS nodes. Radio resources such as frequency allocation, dynamic channel allocation, and data collection for radio resource modeling are terminated in the BSC. The BSC speaks with BTS nodes over the A-bis interface, the mobile switching center over the A interface, and optionally to the serving GPRS support node over the Gb interface. [20]

MSC - The mobile switching center (MSC) manages one or more BSC nodes and terminates the GSM mobile network to the conventional telephone network. Management of connection oriented network resources, such as calls are terminated in the MSC. The MSC offers interfaces to the PSTN (public switched telephone network) and home location register among other optional components. [20]

HLR - The home location register (HLR) provides a user registry of all SIM modules registered on the network. Replicating the information stored in the SIM card, the HLR provides the network with a list of authorized users, and unique handles to determine the mobile extension and the cryptographic keys for secure communications. [20]

SGSN / GGSN - The serving GPRS support node (SGSN) and the gateway GPRS support node (GGSN) comprise GPRS support nodes (GSN) which handle the packet data portions of the network. The SGSN interfaces with the BSC to intercept traffic bound for packet networks and interfaces with the GGSN. The GGSN aggregates traffic from the SGSN and terminates the data services path of the GSM mobile network to an IP or similar data network. [20]

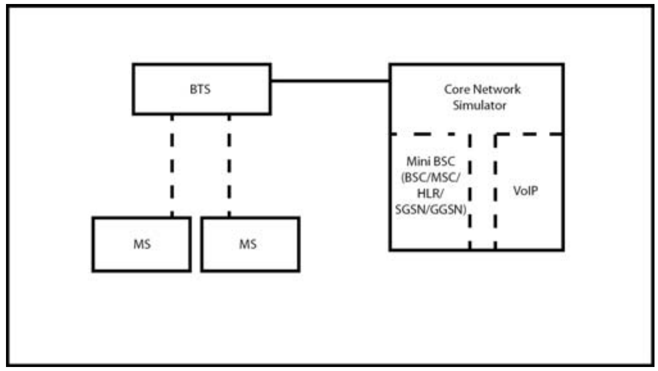

Figure 3. Ideal Simplified GSM Network Component Architecture

While many of these modules are segregated to allow a commercial network to perform optimally with production traffic levels and offer scalability of a widely dispersed high-traffic system, for the purposes of a minimally operable network, many components can be consolidated or replaced with emulated modules. Critical components designed to ensure scalability routing and delivering user data can be greatly simplified if the physical footprint of the network is decreased. As such, these consolidated modules can be reduced in functionality and complexity to simply decode traffic on the Um interface and immediately present it to the applicable back-haul networks.

Device Availability

A formidable portion of the viability in operating a communications system using GSM can be credited to the variety of options in available handsets. Regardless of the feature set or options offered by a specific handset, all handsets are enabled by the consolidation of common designs. We claim unique flexibility in deploying such a system with the observation that all types of GSM handsets can be used in a single network environment while flexibly allocating network resources based on the specific and individual needs of each terminal.

Empowering the viability of a low-cost GSM ecosystem is the ubiquity of inexpensive GSM handsets. Conforming to the standards regarding air interface communications, GSM handsets offer a number of different user services in one or more standard GSM bands. Unprecedented market proliferation of devices supporting the standard have consolidated functional designs into only a few semiconductor devices, and the costs of fully functional handsets and embedded modules into the low tens of dollars. However, on the higher end, the most advanced and full-featured mobile computation devices are integrated with the GSM cellular standard. Although more costly, these devices can be computationally equivalent to recent vintage desktop PCs with the benefits of highly integrated physical designs, considerable optimizations towards power usage, and wireless network interfaces.

4. SYSTEM IMPLEMENTATION

The GSM Radio

The front end of our network is implemented using a hardware modified commercial product, the IP.Access nanoBTS. The nanoBTS is a carrier-grade radio network access device (or BTS), and implements the infrastructure side of the GSM radio link. As with all infrastructure radio nodes in a GSM network, the nanoBTS presents a radio interface implementing the Um link to the handsets (or MS) connected to the network and provides an A-bis interface to the BSC. The radio is capable of producing a carrier on a single ARFCN which implements a single TRX in the GSM band specific to the device variant. Variations of the nanoBTS are available for each of the standard GSM bands (850/900/1800/1900). Unique to the nanoBTS, the A-bis interface is implemented over IP and is presented to the core network upstream via an Ethernet interface. This adaptation to the standard is unique in commercial GSM infrastructure equipment, as conventional A-bis links are implemented using intrinsically reliable yet more cumbersome TDM links such as T1/E1 frame-based carriers. While adopting this adaptation better suits the commercial application of the nanoBTS to rapid deployment into existing IP-backhauled infrastructure, it provides us with a lightweight and ubiquitous hardware interface through which we can connect with the device.

Figure 4. An unmodified nanoBTS, the radio controls board, an ARM Linux SBC for controls. Together, these components implement a complete GSM network.

In addition to modifying the signaling portions of the A-bis interface to operate over TCP/IP, the nanoBTS transports real-time data over RTP (realtime transport protocol) in a manner similar to most VoIP networks. In a commercial environment, these RTP sessions are aggregated in the BSC, which presents the proper time-slotted delivery of voice and data packets to the upstream core network, but for our purposes RTP sessions can be looped back into our nanoBTS (to support a call between two handsets served by the BTS), or can be routed to an intermediary agent for further routing (for out-of-cell calls or packet data sessions). It should be noted that in the former case, only operations and management link data is transferred upstream to the acting core network controller.

While the architecture of the GSM ecosystem supports great flexibility to optimize a commercial installation for supporting a large number of users, in a usage scenario requiring single radio access node it is only necessary to implement the minimal subset of the network services such as to properly communicate over the A-bis link to the nanoBTS. To perform these requisite communications, we use OpenBSC: a robust open-source software, implementing a BSC providing A-bis interfaces to a number of commercial BTS products, as well as minimal MSC, HLR, and SGSN functions. OpenBSC operates under any Linux-type environment, and is exceptionally capable of managing small network installations with minimal computational and storage resources.

Adaptations for Flight

To enable deployment on a small-scale UAV, we make considerations to optimize two critical resources: power and payload weight. We consolidate physical and operational components to optimize resources such that we can operate within the limitations of our available payload-bearing aircraft, reducing weight to an absolute minimum required components and power usage to levels negligible for the mission power budget. As a minimal operating network requires one base station unit and an attached control system to perform the functions of the GSM/GPRS core network, we model our system to include these required components. An unmodified nanoBTS weighs approximately 2.7kg, and a conventional PC used for emulating the core network is well beyond the power and mass budget for aerial deployment.

To reduce payload, we physically modify the nanoBTS to remove unnecessary weight contributed from the industrial casing. Removal of the casing reduces the mass to approximately 260 grams, considerably lower mass acceptable for flight. While the casing provides structural protection, careful observation of the component layout of the radio control board suggests that RF shielding and proper heat management prevents the radio from performing optimally. To address these issues, we design and fabricate a custom casing to protect the radio control board, dissipate heat from critical components, and properly shield functional divisions in the unit.

While physical adaptations can address the mass considerations of the radio unit, resolving the issue of core network emulation presents difficulty. While the continued use of a conventional PC running the core network control software allows communications backhauled from the GSM network to connect to other services available on the PC or LAN, flight payload restrictions render aerial deployment infeasible. However, if all communications are to be exclusively terminated within the GSM network, the feasibility of embedded core network emulation becomes possible.

To perform preliminary tests, we address the first usage scenario by introducing a proprietary Ethernet bridge radio between the core network emulation PC and the aerial base station. Using this configuration, the direct link between the aerial base station and the PC is extended, allowing a remotely tethered operation of the base station. While the payload requirements of the UAV are not optimized by the inclusion of the radio board and the Ethernet bridge radio, the ground PC ensures complete backhaul functionality. For network traffic originating and terminating in the GSM network, only signaling data is carried to the ground based core network emulator; for communications requiring external connectivity, payload data is transported to the core network emulator and terminated to the local network. In this configuration, the aerial base station can operate reliably while connected to ground services within the link budget restrictions of the Ethernet bridge radio, and as such still requires ground connectivity to signal all communications and services provided by the network.

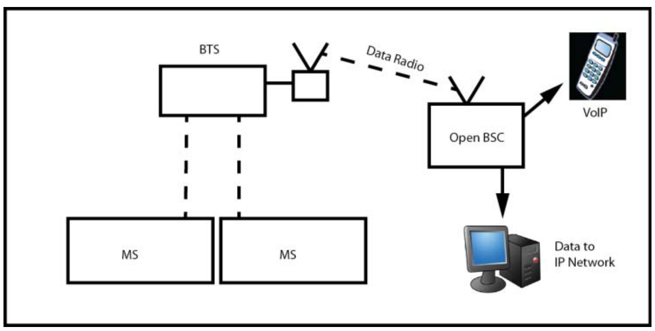

Figure 5. Tethered operation of AirGSM system: backhauling to ground systems takes place via Ethernet bridge

In an effort to have a fully contained network without the requirement of tethered operation, we implement the core network emulator on an embedded Linux development board. We physically include and package an ARM based control system with the core network emulation software with the radio control board into a self-contained autonomous GSM network. In addition to reducing the weight and ground tethering requirements, consolidation of the controls to on board embedded processors reduces the system total power dissipation to 15.4W. It should be noted that while resource-optimized, this configuration does not allow for terminations of communications outside of the GSM network.

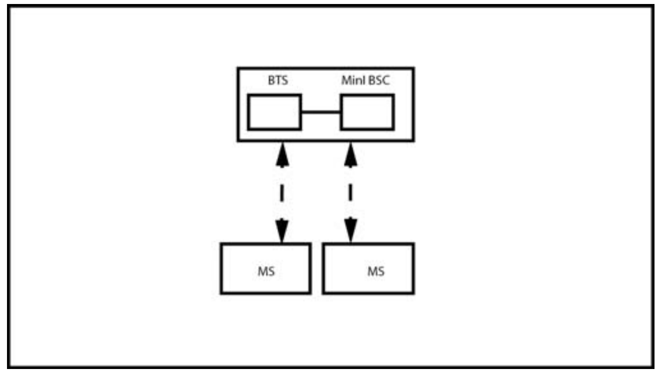

Figure 6. Free-standing operation of AirGSM. All communications are terminated in the GSM network; no external interfaces are required.

Carrier Aircraft

The UAV constructed to meet the design and payload requirements outlined by the specifications above utilizes a unique frame design in an eight bladed multi-rotor helicopter configuration. This propeller setup serves a dual purpose, both ensuring maximum thrust to increase payload, as well as providing a redundant fail-safe in the air. The craft is capable of safe flight with one or even two motors inoperable. Constructed of lightweight carbon fiber and aluminum, the frame was designed to maximize both lift and flight time to ensure that the GSM base station stays online for the required mission duration. The device relies on lithium polymer composite batteries, which balance tradeoffs between weight and capacity to optimize both flight time and payload. The UAV has been tested with an altitude ceiling in excess of 700 meters, far greater than our target altitude and is sufficient for creating our own GSM network with a reasonable coverage radius. [22]

To manage flight operations, a wireless link between the control system on board and a ground station allow real time communication between an operating team and the device in the air. Diagnostic information including GPS coordinates, altitude, battery voltage and aircraft orientation against an artificial horizon allow precise control of the UAV at all times. Additionally, a variety of autopilot modes can be selected remotely, including an altitude hold and a GPS position lock that maintains a hovering position within an allotted GPS guided location window. Manual control of the UAV while in flight is accomplished over a 2.4 GHz radio link, and can be used to adjust critical flight parameters.

5. PERFORMANCE TESTS

Designed to connect communications nodes on the ground, the AirGSM system is configured to provide operable network signal from the ground. Upon confirmation of a functional radio carrier, the UAV is deployed and either manually or automatically placed into a holding pattern with sufficient coverage and visibility of the target coverage area. From the holding position, the UAV is monitored from the ground using the flight control link while the GSM network provides coverage to ground terminals

The basic services of the GSM network system include terminating voice calls and SMS short messages. Due to the error and channel coding of the air interface, we expect these functions to perform comparably as signal strength degrades to the minimum sensitivity of the radio hardware. Our test environment is realized by the nanoBTS radio configured to 23 dbm output power (the maximum for the band) and a specified receive sensitivity of -108dbm. We configure our network to have a symmetric transmission power, though it is expected that the sensitivity of the MS is lower than the BTS.

Using freespace propagation calculations and headroom considerations for an acceptable fade margin of 10db, our expected link at 1950 MHz downlink carrier with a clear Fresnel zone and negligible noise/interference should provide a stable connection at a range of 3.4km.

In actual testing, with the AirGSM platform at 42 meters above ground level, we were able to close an unobstructed communications link at approximately 1.35 km with a received power of -101 dbm as reported by the handset during active communication. Within a 100m radius, received power levels from the test handset varied between -78 dbm and -85 dbm received signal strength, demonstrating the likely environmental contributions to influences in power/range as well as handset design and radio effects from handheld operation.

Per the GSM specifications, full rate data transmission is only available over 25% of the cell coverage area due to radio performance requirements. Closing a link during a data session provided less stable results, as even voice/SMS performance became intermittent at ranges beyond 1.5km and transmission errors are likely to influence transmission rates.

6. Competing Radio Technologies

Wi-Fi

The most commoditized wireless radio technology devices available are products conforming to the Wi-Fi standard. Created to enable short distance, high-throughput local network connectivity, Wi-Fi offers wireless adaptations mirroring the Ethernet local area network connection standard. Many products support the shared-spectrum wideband data network service, including some mobile handsets. Despite reasonably low cost and ubiquitous deployment, Wi-Fi based networks present two principal disadvantages over cellular technologies.

While Wi-Fi has seen great success in desktop and mobile computation products, traditionally deployment into integrated handsets has been relegated to higher-end mobile phones. Wi-Fi support in many common easily interfaced and low power embedded devices is lacking, as support for the power-intensive radios and wideband protocol is unsuitable for resource-limited applications. Principally, Wi-Fi has been integrated into devices as a short-distance connectivity substitute, designed to provide throughput and low cost at the expense of range, power, and integration flexibility. To this end, Wi-Fi has only been considered in commercial devices with the intent of terminating wide bandwidth communications, not in establishing basic connectivity.

In addition to the principal disadvantages of device selection, Wi-Fi is disadvantaged as a long distance radio carrier compared to GSM. GSM's managed spectrum, narrow bandwidth, and intrinsic support for high transmission powers (many devices support the maximum allowed 33 dbm) in embedded devices presents a notable advantages over most Wi-Fi implementations. By comparison, Wi-Fi operates in an unorganized shared-use band, with most devices transmitting at low powers (conventionally 10 to 17 dbm) across the specification-mandated 20 MHz bandwidth. GSM wireless links distribute their considerably larger power across approximately 1/100 of the bandwidth, posing both the potential for a greater link budget and greater distance from a noise floor inherently quieter from reserved spectrum use.

Proprietary Data Radio

As an alternative to wireless technologies derived from Ethernet topologies, numerous variations of proprietary data radio products exist for closing communications links for data communications (which can be used to carry other services) over large distances. Generally narrow band technologies operating in shared, multiuser ISM bands, these radios generally connect serial data over point-to-point links. While the link budgets of these devices compare favorably with the link budgets of the GSM air interface and the minimum system cost can be comparable, there are numerous disadvantages regarding integrated services and scalability.

Proprietary data radios interface poorly with integrated handsets, and many modern integrated handsets offer no way to extend integrated services over a serial port. While embedded applications and large-scale computational terminals adapt well to serial data interfaces, the cost and complexity of these radio installations, as not only are costly radios required for every terminal, but many configurations do not offer repeating or aggregation services in the radio, requiring the installation and support of one per of radios per link.

Conventional Land/Mobile Radio

Conventional Land/Mobile Radio (LMR) are frequently considered for ad-hoc field communications due to convenient form factor and considerable range. However, LMR sets have been relegated to simplex voice operation, and have failed to provide more advanced services expected of most handset applications and even advanced installations have failed to provide more than basic data services. Comparable to the operation of amateur radio or licensed band mobile radio, these installations close link with considerably high transmission powers (up to 37 dbm in handheld units, 47 dbm in mobile units) over narrow bandwidths at low frequencies. Although posing advantages in range, the lack of services and flexibility provided and the resulting absence in integrated platforms disadvantages LMR against high node-count networks, low resource installations, or applications beyond simplex voice.

Satellite Telephony

Satellite telephony presents a formidable competitive technology to AirGSM, as many cellular telephony systems closely mirror the protocols and communications technologies as well as the integration models of GSM. While many similarities exist in the services provided, satellite terminals generally require significantly more power and resources to close links to orbital base stations. These greater resources can be seen in power and weight costs of terminal equipment, and as a result, fewer variations of handsets are available on the market. These comparatively high costs exculpate deployments large numbers of low-importance nodes, or even all but the most critical communications.

These higher costs are not without benefits, as most satellite based communications systems can effectively close links between handsets over considerable distances spanning the globe and can be cost-justified in these installations. However for more localized communications, AirGSM and conventional mobile handsets provide greater flexibility and lower cost.

7. CONCLUSIONS

We successfully demonstrate the feasibility of operating a single cell GSM network in a compact physical platform suitable for aerial deployment on a low-cost UAV. In so doing, we argue that the combined use of such an infrastructure-side implementation combined with efficiently integrated commercial cellular handsets, cost and resource efficient communications can be established between a heterogeneous selection of terminal devices, ranging from event-driven telemetry to interactive voice and data communications. We demonstrate a practical usage scenario, and present practical results from field deployment, as well as provide a discussion in regard to competing technologies.

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