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# FemtoStar

The Open Satellite Platform for Communications from, and with, anywhere and anyone on planet earth.

In recent years, almost every conceivable category of product which has the potential to pose a threat to the privacy of its users has seen significant development of privacy-aware alternatives. In mobile communications systems, however, such development has been limited, and in almost all cases, privacy-aware mobile communications options beyond the range of one's own WiFi network are not available. Community-run mesh networks don't work if each user is one of a handful of nodes in their entire country, solutions based on amateur radio solve the range problem but require users to be licensed and, in most countries, ban the use of encryption, and privacy-respecting access to commercial cellular networks is hampered by network standards designed such that tracking individual users as they move around the network is essential to their basic operation.

In light of these issues, it is apparent that any practical privacy-respecting mobile communications system must cover a large area even without community-run local infrastructure or the "critical mass" of widespread adoption required by existing mesh network efforts, must not be limited by the per-user licensing or usage restrictions of amateur radio, and must be designed from the ground up with the privacy and security of its users in mind. The FemtoStar project has sought to architect and develop such a system, and the results of our efforts to date are described in this document.

# *the system*

FemtoStar is a proposed satellite communications system, focused on flexibility, cost-effectiveness, and above all, security, privacy, and freedom for its users. Every component of the system is designed with these principles in mind, from the highly-reconfigurable GNU/Linux-powered communications payload aboard the satellite, to its inexpensively-launchable spacecraft bus built to the PocketQube form factor, to the fully-free-software-powered, open-hardware user terminal. A network of one or more low-earth-orbit satellites provides service to user terminals within their continuously-moving coverage area, and, over the course of approximately twelve hours, each satellite will cover the entire earth once. This means that even with one satellite, FemtoStar's coverage is global. Additional satellites increase the how frequently coverage is available in any given place, not the size of the coverage area.

FemtoStar provides secure, private, and censorship-resistant data communications services, both in real-time (when users share a satellite footprint with a ground station, or when two users in the same footprint are communicating) and on a store-and-forward basis (when this is not the case). User terminals do not identify themselves to the FemtoStar network, and the network is designed specifically to support this (including for billing purposes). The FemtoStar network also has very little ability to geolocate terminals. The system is capable of determining only that you have provided payment for service - not who or where you are.

# *the satellite*

At the heart of the FemtoStar system is the focus of our current development work - is its eponymous satellite, the FemtoStar. With a 1p or 1.5p (depending mostly on the inclusion of a propulsion system) PocketQube form factor, and a mass measured in hundreds of grams as opposed to hundreds of kilograms, it would be the most cost-effective communications satellite ever built. The FemtoStar satellite consists of two major systems - the spacecraft bus and the communications payload.

The spacecraft bus includes a radiation-tolerant microcontroller, a deployable solar array, batteries, power management, and magnetorquer-based attitude control. The solar array, designed on a flexible, fold-out support, provides over 30 watts of peak power. On variants with propulsion, the spacecraft bus also incorporates a small electric thruster.

The communications payload (to which much of our work to date has been devoted), attached to the bottom of the spacecraft bus, includes eight fold-out antenna panels around a central core. All microwave circuitry mounted on the rear of these panels.

The core houses a compact stack of boards, including an ARM-based payload computer based on a commercial SoC and flash storage for store-and-forward services.

Based on our development effort to date, we believe the FemtoStar satellite could be built for less than $6000, and could be relatively easily mass-produced. Assuming a 1p PocketQube form factor, Alba Orbital currently prices launch for a 1p satellite at €25,000. In comparison, construction and launch of a traditional geostationary communications satellite can easily eclipse the $100,000,000 mark, while medium-sized low-earth-orbit satellites start in the millions, and even satellites in traditional smallsat form factors (such as the 3U cubesat) typically cost hundreds of thousands of dollars. The dramatic cost reduction of the FemtoStar design and the PocketQube form factor in comparison to traditional communications satellites are what renders feasible a specialized satellite communications network such as the one proposed in this document.

# *the network*

A key element of the FemtoStar system is the highly-flexible nature of the network. The FemtoStar network can be entirely operational with only one satellite, can operate entirely independently of ground-station infrastructure, and can be optionally extended, as part of the initial network or at a later date, with additional satellites for more frequent coverage, all the way up to a global constellation with continuous coverage, as funding allows.

In most satellite communications systems, the satellite serves simply as a connection between users and a ground station. In some systems, such as Iridium, traffic can be routed between users entirely via the space segment, while a ground station is still used for functions such as subscriber billing. In others, satellites carry only simple transponders, serving only to repeat signals from users to ground stations and vice versa. However, in nearly all systems, an extremely clear distinction is made between feeder links - used by the satellite's operators to connect the satellite to terrestrial networks - and service links - used by subscribers to connect their terminal to the satellite.

FemtoStar does not make this distinction. When servicing real-time sessions, the FemtoStar satellite simply routes traffic between a pair of connected terminals within its footprint. These points could be two users communicating directly, a user communicating with a FemtoStar-owned ground station to access a terrestrial network, or even a user communicating with a third-party ground station providing its own services over FemtoStar satellites. Additionally, community members willing to connect their FemtoStar terminal to the internet and run "core services" compatible with those offered by official ground stations could expand FemtoStar's coverage to the entire region (more than 2000 kilometers in radius) around them, reducing the area in which other users must rely on store-and-forward service only.

# *the service*

FemtoStar is designed to provide two broad classes of narrowband communications services - real-time and store-and-forward.

Real-time services use the satellite as a router between devices within its coverage, providing a low-latency link between pairs or multicast groups of terminals. In order to encourage worldwide availability of of "core" services such as messaging, weather, narrowband internet access, and news, the FemtoStar project would develop a standardized "core services" set, implemented on their own ground stations, and available for installation on a standard FemtoStar terminal. This would allow third-party ground stations to be operated, allowing for redundancy in ground infrastructure, and coverage in regions where official ground stations are not available. Operators of these third-party ground stations would also be able to operate non-standard real-time services, allowing anyone, with or without an internet connection, to use FemtoStar as an open platform to provide their own services to users up to 2000 kilometers away.

Store-and-forward services are fallback versions of FemtoStar's core services, running on the satellite itself when a ground station supporting real-time core services is not available. Store-and-forward services allow messages, files, and other data to be temporarily stored on the satellite itself as it orbits from a user without ground station coverage to a ground station where they can be forwarded, or from a ground station updating the on-satellite data to a user able to download it later. Additionally, store-and-forward messaging between users can be done entirely without a ground station, ensuring that the satellite remains available for global user-to-user messaging regardless of the functionality of any other infrastructure. While support for third-party applications on the satellite itself, in the vein of nonstandard real-time services, is not currently proposed, an API for custom development using store-and-forward messaging could be made available.

# *the security*

FemtoStar's focus on security, privacy, and software freedom is reflected in numerous design choices related to how the terminal interacts with the network. Whereas many satellite networks require terminals to determine their location and periodically report it to the network, or are designed to otherwise geolocate the terminal, the FemtoStar network is designed specifically to avoid geolocation of users. Terminals slightly randomize the latency of their responses to the network, preventing the network from determining the terminal's distance from the satellite, and correct for the doppler shift caused by the satellite's movement relative to the terminal as it passes overhead, preventing the network from determining the velocity of the terminal relative to the satellite.

Still, extremely coarse knowledge of terminal location based simply on the known position of the satellite and which beam the terminal is using (giving an extremely vague indication of the angle between the satellite and the terminal) is unavoidable. Because of this, users must not be individually identifiable, as they are in effectively all existing telecommunications networks. As such, terminals do not identify themselves to the network, instead using randomized transaction identifiers to identify individual interactions with the satellite rather than hardware or users.

In order to allow for unidentified users, billing is handled using a prepaid credit system. Unlike just about any other satellite network, FemtoStar handles credit processing on the satellite itself, allowing billing (and the service it pays for) to continue as usual, even with no ground station available. FemtoStar credits are simply signed keys, issued by the satellite's operator (presumably the FemtoStar project), stored on the user's terminal, and provided as payment when service is consumed - they aren't tied to any account, and they never expire. The satellite simply internally marks credit keys as consumed, and eventually returns the key to the issuer for reissue under a new signature. Newly-issued credits could be sold for cryptocurrency or via traditional payment methods, included with hardware, given away, or otherwise distributed by the satellite's operator, while unused credits could be traded freely between users.

***Questions? Comments? Want to chat about satellites?***

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