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SIMPLIFIED FEMTO-SATELLITE OPERATIONS FOR DISASTER MANAGEMENT MISSIONS

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The reduction in size of satellites is reaching at the range of femto-satellites, i.e. satellites less than 100 grams in mass. One of the key points to achieve such a reduction is to simplify the design of the satellite, but also to simplify their mission operation. In the present work, a simplified method for responsive femto-satellite operations is presented which is able to deal with the main types of disaster management tasks. Then, a mission is easy to program using a few default functionalities in everyone of a cooperative satellite swarm giving a list of coordinates. The protocol is able to update the list for adaptive missions which are based on coordinates. This feature would allow an easy control for the first responders when they are in the field in the beginning of an emergency. These satellites could send real-time pictures to the first responders agents, without the need of a complex ground station infrastructure, until the help arrives.

I. INTRODUCCTION

Nowadays, large and lasting satellites in Disaster Management (DM) are used [1] [2]; they are located in orbits like Low Earth Orbits around *700 km or Geostationary Earth Orbits at 35,786 km in height. Such orbits are becoming saturated especially by Telecom satellites. Maintaining a satellite in such conditions, if they were only dedicated to DM, would be a continuous maintenance waste during the periods in which nothing happens and therefore, a misuse of orbit and resources

The use of femto-satellites will permit, under the *Space Payload Paradigm* [3], lowering the operating costs in disaster management and even to do dedicated launches to a single emergency, and so no satellite would go into orbit until an actual emergency happened as a space responsive action.

To reduce the satellite size, it is mandatory not only to simplify their design, but also their mission operation modes. With a minimal number of subsystems like attitude control, high gain modem, high accuracy attitude and position determination, power management, etc. it is possible to design missions that cover many types of disasters. Thus the cost of assistance during an emergency [4] would be low and same whatever the country.

According to Lew Sian in [5], (see Figure 1) the emergency cycle can be divided into four phases after the Impact: **Response**, **Recovery**, **Mitigation** and **Preparedness**. Femto-satellites will be used mainly during the **Response** phase. The first hours after the Impact are essential to minimize disaster effects. Little can be done until support is not established in the **Recovery** phase, but only the people located in the

disaster area could take actions if they could have real-time images and information about the disaster area without the need to have an especial infrastructure.
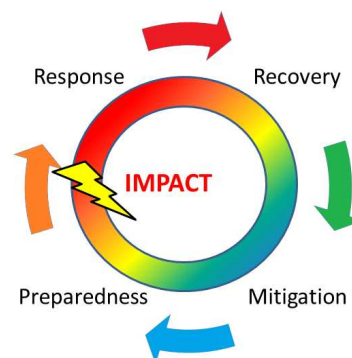

Fig. 1: Disaster management Cycle after the Impact: Response, Recovery, Mitigation and Preparedness.

Femto-satellites would be ready for launch during the **Preparedness** phase. When an emergency happens, depending on the type of emergency, femto-satellites would be sent to an appropriate orbit (depending of several factors, specially the geographical location of the disaster area) and they would be fully dedicated to that emergency. The commissioning of these femto-satellites to the orbit represents a very low cost compare to the large satellites, and while on Earth, launch stations are cheap to maintain. Several femto-satellites can be launched simultaneously from multiple geographic locations in order to reduce the revisit time, and taking pictures as soon as possible. Another option is to launch several from the same geographical location but spaced a few hours between them. Each launcher could send up to six femto-satellites in the same injection forming a swarm.

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Currently, these femto-satellites are designed to be injected into orbit in two hours [3], passing over the disaster area at most one day wherever the geographical location. The process would be to release a helium-filled balloon into the stratosphere, carrying a small tube containing a rocket. This rocket would put into orbit one or more femto-satellites. Each femto-satellite gives 13 laps before passing again above the emergency every day. A femto-satellite constellation would significantly reduce the revisit time. At the height proposed for the femto-satellites, the disaster area is visible for about 6 minutes and wireless communications are possible. Whenever a femto-satellite passes over the emergency, it would take pictures and send them both through wireless to anyone inside a 50 km footprint and after that, to any scheduled ground station.

II. TASK ANALYSIS FOR DISASTER MANAGEMENT

II.I Earth Observation and Relay

Most tasks that a Low Earth Orbit satellite performs in disaster management issues are related to **Earth Observation** and **Data Relay**. The **Earth Observation** task consists in acquiring images from the disaster area and sending them to the decision makers. The **Data Relay** task consists in providing basic communications to the first responders. During the emergency, basic services could not be restored after days or even weeks. This second type of task can only be provided with satellite networks such as [Iridium](http://www.iridium.com/)[†] or [SPOT](http://international.findmespot.com/)[‡]. However, if involved people do not have appropriate receptors this procedure is of no use to them, at least until they get outside help.

Once the information is acquired by the satellite, its applications in disaster management mainly depend on the specifications of the on-board sensors. According to Luis Izquierdo-Mesa in [6], the types of disasters that a femto-satellite can address are: earthquake, drought, cyclone, fire, flood, landslide, volcano, etc. These categories of disasters do not generally evolve over periods longer than one week (except volcanoes or drought).

II.II Initial hypotheses

To perform the following task analysis, we have assumed several hypotheses:

- The swarm will be dedicated to a single emergency and its mission can be updated at any moment during the mission.
- Each satellite will perform at least a revisit each day because of the very low orbit adopted. Of course, a constellation could reduce the revisit time.

[†] http://www.iridium.com/
[‡] http://international.findmespot.com/

- Because we are proposing a very low orbit, the femto-satellite aerodynamic drag will reduce its useful life between 1 or 2 weeks.
- The femto-satellite viewing horizon cannot exceed about 2,000 km because of the very low orbit.
- Not always will the satellite transit just above the disaster area. Images may be seen at an angle. Depending on the application, images should be corrected on the ground.
- The femto-satellite has a quite limited energy and will only be active while taking images of the disaster and downloading them. The rest of time, the femto-satellite will stay in and idle state.
- Each femto-satellite has not solar-cells and battery has a very limited duration. It will be necessary an energy budget for a given mission, especially in adaptive missions.
- Each femto-satellite uses a high power wireless modem so a ground station does not requires a huge installation.
- There are two download modes: a slow but long range mode with 200 km footprint, and a fast, short range 50 km footprint mode.
- The information to be transmitted is not encrypted because it is of global interest.

II.III The basic process of a femto-satellite

In short, the basic procedures that a satellite dedicated to disaster management should always do is to know where the satellite is relative to a coordinate, change the attitude of the satellite so that when the interest point is in sight it could perform a tracking maneuver, activate the sensors and acquire information. This information can be downloaded immediately to first responders, and/or stored to be subsequently downloaded to the scheduled ground stations. The download to ground stations follows the same procedures. The download process can be divided into two phases. In the first phase the satellite establishes the link which verifies that the ground station is listening; if the link is established, the femto-satellite can pass to a fast download mode because it ensures that the ground station is well within the 50 km footprint. If no link is established, the femto-satellite sends the information at the slower data rate to the 200 km footprint. If a link is established with the ground station, not only a faster download is possible, but it allows also to modify the mission if the password is provided.

II.IV Simplified list of agents

Fig. 2 shows all working coordinates needed. All agents are considered as coordinates. The interest point

and first responder are the same. There is no procedural difference between ground station and decision makers. The only difference is that the interest point will be given priority and is where the first responder is located. The decision makers will generate a list of coordinates where the first entries will be the interest point.

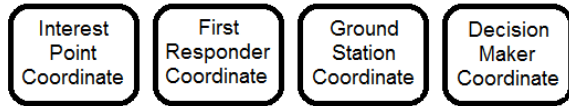| Interest Point Coordinate	First Responder Coordinate	Ground Station Coordinate	Decision Maker Coordinate

Fig. 2: Types of coordinates.

The rest of coordinates will be ground station coordinates, as there may be more than one, there is no order of priority between them because the femto-satellite will follow an algorithm to establish the link with the nearest ground station. The link will be kept until the end even if another ground station has become the closest in between. A change of ground station in the middle of the download would be a waste of time due to the time needed to establish the link with another ground station, and because the first download would be fractionate. The ground station distribution policy that will be used in the list is that they should be spread throughout the world and separated by over 1,000 kilometers. Only a number of ground stations to ensure enough time to download all the information will be set in the list, but no more, to avoid wasting the femto-satellite battery. It is useless to set ground station coordinates in the list that are very close to each other because the femto-satellite just will follow the first one is in sight.

Each femto-satellite is programmed so that when all the information has been sent to the ground, it would repeat the download if necessary. Nevertheless, if many ground stations were in the list, the acquired images would be downloaded repeatedly until they are updated in the next revisit, but this would rapidly drain the battery. Thanks to the infrastructure provided by the Internet today, it is much better to share information and download it once (not counting the time it is downloaded to the first responders when passing over the disaster area because it is likely that communications are upset) and managed by a single agency such as UN-SPIDER [5].

III. SIMPLIFIED METHOD FOR FEMTO-SATELLITE OPERATIONS
III.I The Simplified Method

In what follows, a simplified method for femto-satellite operations is presented. This method simplifies the operation almost in any disaster management mission with a minimum number of subsystems in such a way that the satellite is simple and lightweight.

- Each femto-satellite will have a list of eight geographical coordinates.
- The first coordinate will be the point of interest that has absolute priority over other coordinates. First responders are near this coordinate by definition.
- The rest of coordinates are ground stations to download the information. Decision makers or other agents could be placed in this coordinates; the only that a femto-satellite will take contact.
- Each femto-satellite will maintain an attitude as aerodynamic as possible to lengthen its life.
- If a femto-satellite sees any coordinate of the list, it would leave the aerodynamic attitude and point toward that coordinate, following it until it is not in sight.
- When a coordinate becomes out of reach of a femto-satellite, it will point to the nearest coordinate in the list if any; otherwise, it would return to an aerodynamic attitude to extend the useful time in orbit.
- When a femto-satellite is following a coordinate, it will try to establish a fast downlink with a 50 km footprint.
- If the link succeeds, wireless service will be provided to this area; then the list could be updated from ground (a password should be provided to the satellite).
- If the satellite does not succeed in establishing the link, information would be slowly broadcasted to a 200 km footprint.
- If the volume of information is small, it will be repeated to ensure that it reaches the receiver; this procedure would be followed until the information is updated in the next revisit.
- If a coordinate is followed, it will be kept even if there is another coordinate that has become nearer in order to optimize the download time.
- If a coordinate is followed but the interest point coordinate enters in sight, the link would be interrupted and the femto-satellite would acquire/relay information related to the disaster.
- It is possible to acquire and establish a link if the interest point has a wireless equipment that works as a ground station; this case is used to report directly to the first responder; if not, the information is just broadcasted.

III.II Considerations

It is mandatory to run simulations to ensure that each femto-satellite will have enough battery to accomplish with its schedule. We have employed the open source tool[§] **Moon2.0** to do so as showed in Fig. 3. The example shows the simplest DM mission based on the Sri Lanka tsunami impact in 2004. This figure also sows the simulation of the femto-satellite sensor that is a High Resolution camera. This single femto-satellite has a list with **Matara** (*Sri Lanka*) as the interest point and only one ground station in **Mas Palomas** (*Spain*). The simulation spans for 8 days. Two ours and 20 minutes after the launch, the first responders got real-time pictures of the disaster and new information was downloaded to the first responders everyday. More than 30 contacts were established with Mas Palomas ground station during the mission. Thanks to the low use of the attitude control, the femto-satellite least for 8 days instead of 6 days.
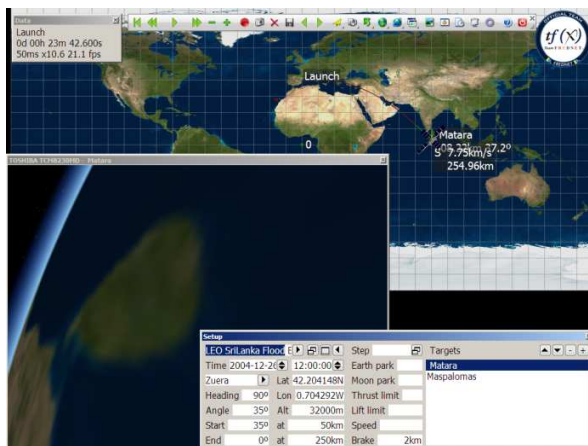

Fig. 3: Simulation of a femto-satellite in the Sri Lanka - Tsunami impact (2004)

Changes on the objectives during the mission can affect the energy use for a given femto-satellite. These changes, usually done by the decision makers during the emergency are unpredictable. They should recalculate the simulation to determine the remaining femto-satellite energy and the best way to employ it.

The number of ground stations and the places should be considered. The higher number of ground stations the greater volume of information downloaded, but also the higher power consumption and the shorter the mission time. Also a large number of stations allows to distribute the same information around the world but it is always better to centralize the information on ground (for example via UN-SPIDER).

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§ http://code.google.com/p/moon-20/

It is interesting that ground stations are not all together because only the nearest will be used. Now, more than one ground station placed inside the 50 km footprint can receive the same information. Ground stations should be located after the disaster in the line of flight of the swarm (Usually Eastward) separated at least 1,000 km from the disaster area to have the information available as soon as possible to the decision makers.

III.III Optimal configuration

Obviously, the optimal configuration is one in which the point of interest coincides with the ground station and no other ground stations are in the list. In this way real-time information is sent to the first responder each day, the one who need it most, would spend as little energy as possible and lengthen the life of each femto-satellite two days more. Normally, first responder would not have the resources to manage the crisis; this task must be done by the remotely-located decision makers that can establish a better plan of action because they have better global information, intact facilities and resources. With the use of femto-satellites, decision makers would not need a big infrastructure to communicate with the swarm. Being in a low orbit, with its directional antenna and high sensitivity modem, each femto-satellite provides a minimum infrastructure to manage the crisis. First responders could manage the situation for the first hours if the link with the femto-satellites is established. They just need an iPad or a Laptop with wireless.

Other configurations are possible: Swarm, Constellations or both.

Several femto-satellites can be launched simultaneously from multiple geographic locations. This way, the higher the number, the smaller the revisit time. If one of these launch stations is near the disaster area, pictures can be taken earlier.

Another option is to launch several from the same geographical location but spaced a few hours between them forming a constellation and reducing the revisit time.

Each launcher could send up to six femto-satellites in the same injection. That way, a swarm is formed. Each femto-satellite could focus in a 50 km footprint when the disaster is large or is changing the position everyday like a fire or a volcano.

Conclusions

Femto-satellites can find a future use by being dedicated to disaster management during the critical first hours. They would help to minimize the immediate effects of a disaster by sending real time information directly to the disaster area first responders. This will greatly reduce the cost of managing a disaster by not having to maintain a larger satellite for several years.

The Method for femto-satellite operations based on a list of coordinates, simplifies the operation almost in any disaster management mission if each femto-satellite has a minimum of subsystems like attitude control, high gain modem, etc. If femto-satellites are cheap then many can be sent into orbit and the launcher is also cheap.

In the future, many launch stations could be distributed around the world. If an emergency occurs a swarm (or a constellation) of these femto-satellites will be sent, dedicated only for this emergency. These orbits are not used currently because of the friction with the high atmosphere. Atmospheric drag would left free the orbit in a matter of a few weeks.

Each femto-satellite provides a minimum infrastructure to manage real-time information for the first hours, leading directly to the first responder, as long as they have just an iPad or a Laptop with wireless.

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