Review of possible replacement strategies of telecom constellations

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Abstract

A bit more than ten years after the deployment of the first constellations of satellites in the field of telecommunications, there is a need to re-populate them with a second generation to ensure the continuity of service. Thales Alenia Space is aware of this need as it has been strongly involved in this field in the late 90's and has always kept an active leading part in the reflections on constellations. In that context, this article presents a review of possible replacement strategies of telecom constellations, after having exposed the complexity of the process by enumerating some of the constraints that apply to this critical phase in terms of service.

1. Introduction

Deployments of the first telecommunications constellations were started about 10 years ago: 5th May 1997 for Iridium and 14th February 1998 for Globalstar. Of course, since this time, both companies have launched spares to maintain both coverage and service. Last spare satellites of such constellations were launched more or less recently: 20th of June 2002 for Iridium and 30th of May and 21st of October 2007 for Globalstar. In the meantime, Globalstar even had to revise its satellite constellation, as announced in August 2003, from the original 6 satellites per plane to a 5 satellites per plane constellation.

The initial life duration of these constellations has been exceeded. So naturally, there is now a critical need to re-populate them with a second generation to ensure the continuity of service and eventually to adapt to a need evolution. Thales Alenia Space is all the more aware of this need as it has been strongly involved in this field in the late 90's and has always kept an active leading part in the reflections on constellations. Furthermore, Thales Alenia Space is main contractor of the Globalstar second generation satellite constellation since late 2006.

The following presents a review of possible replacement strategies of telecom constellations, taking as pure study cases, the renewal of Globalstar and Iridium. More precisely, Section 2 recalls their main characteristics and status at the end of the first generation. Section 3 then highlights the complexity of the process by enumerating some of the constraints that apply to this critical phase in terms of service. Section 4 presents different possible replacement strategies exploiting the peculiarities of the two considered study cases, not only in terms of orbital mechanics of both types of orbits but also in terms of service and system implementation.

2. Main characteristics of analised constellations

As previously mentioned, this paper is illustrated taking as pure study case, both Globalstar and Iridium constellations.

These two constellations although designed for mobile telecommunication purpose, are very different. The following table summarize main elements characterizing both constellations and systems.

	Globalstar	**Iridium**
Number of satellites	Initially 48 and now 40	66
Number of planes	8	6
Constellation type	Walker delta - rosette [1–4]	Rider - Walker star [5]
Altitude	~1414 km	~780 km
Inclination	52 degrees	86.4 degrees
Zone of interest	[-68° ; +68°] (see coverage on Figure 2)	The whole Earth (see coverage on Figure 4)
Type of payload	transparent	On board processing
ISL (inter-satellite links)	None	4 per satellite
Gateways	Many	1 (up to 3 in the past)

To support our analysis, these two systems have been taken because they can be considered as significant due to their difference of principle.

For Globalstar, a mobile terminal is “connected” through a satellite to a gateway which provides connectivity to the public switched telephone network, which performs the classical routing of the communication to the addressee.

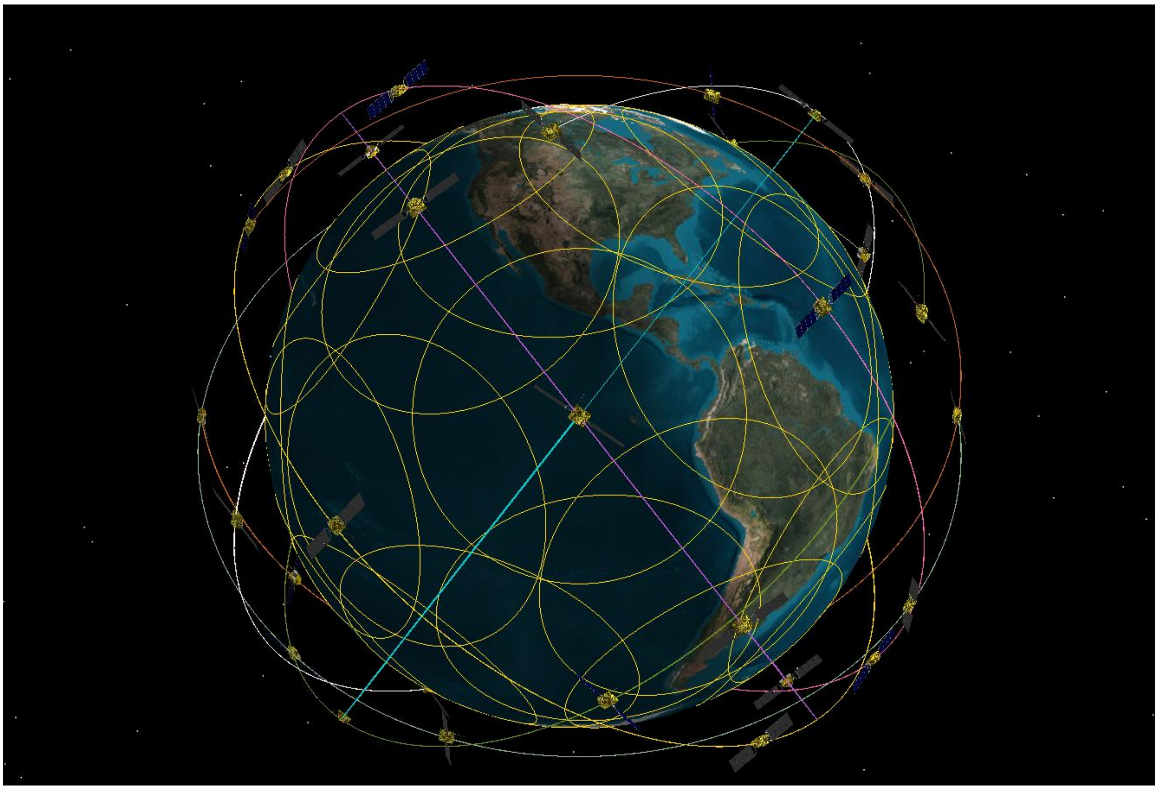


Figure 1: 40 satellites Globalstar constellation with footprints

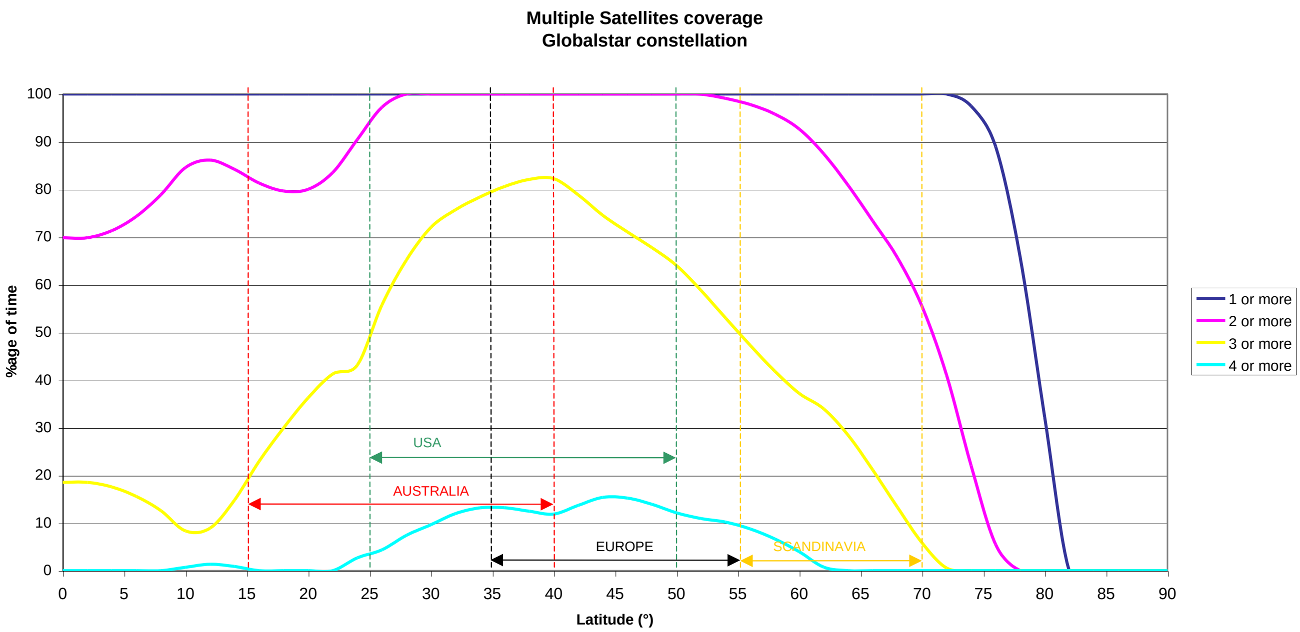


Figure 2: 40 satellites Globalstar constellation coverage performances

In the case of the Iridium system, a mobile terminal can be "connected" to:

1. Another Iridium terminal located in the footprint of the same satellite

2. Another Iridium terminal located in the footprint of another satellite of the constellation. In this case, the communication is routed from satellite to satellite through ISL until the addressee
3. Another terminal (not an Iridium one) located anywhere in the world. In this case, the communication is routed from the initial satellite to the one in visibility of the closest gateway to the addressee. Currently there is only one active gateway in USA, but the initial system contained three gateways and the current number could be increased in the future.

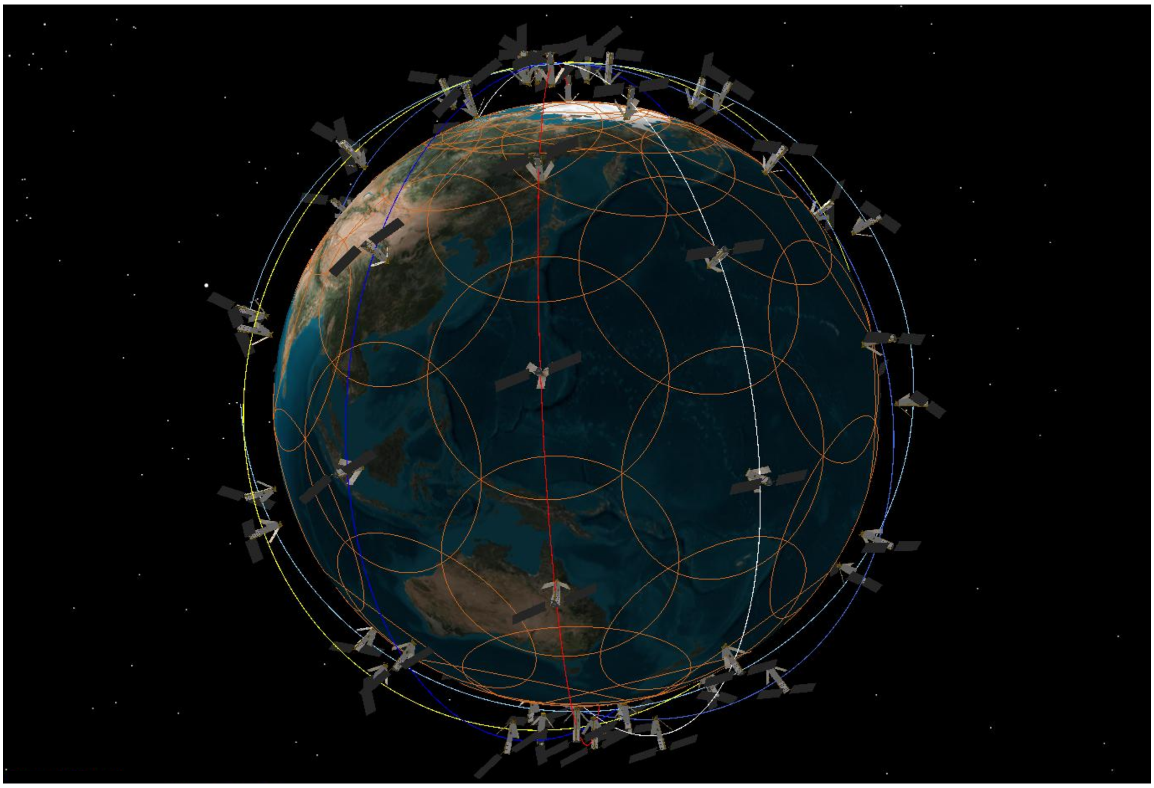


Figure 3: 66 satellites Iridium constellation with footprints

After many spare launches (in total 95 satellites launched by Iridium and 72 launched by Globalstar, including a 12 satellites launch failure in 09-1998) both constellations appear currently complete, in terms of active satellites: 40 for Globalstar and 66 for Iridium.

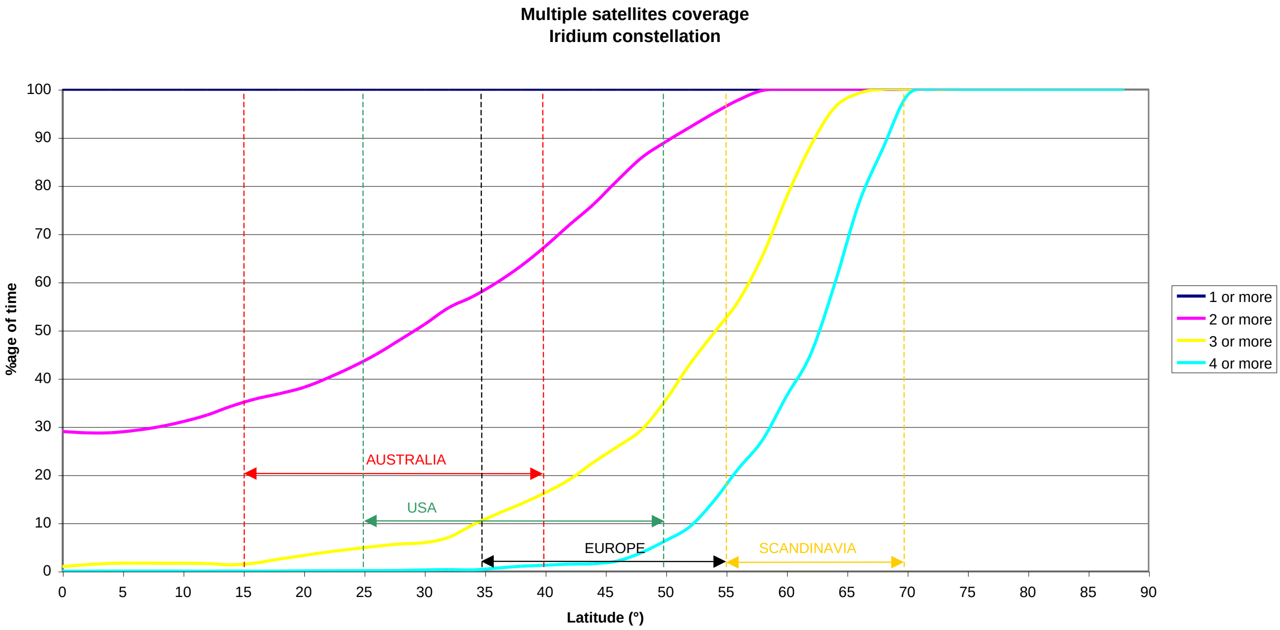


Figure 4: 66 satellites Iridium constellation coverage performances

3. Constraints on such systems renewal

The first constraint appearing in such system renewal is the evolution of the customer need which can take several forms: more services, different business plan, more data rate, different reliability and availability based on experience, etc. The experience acquired during the exploitation of the first generation of its system allowed the constellation owner to adjust his business plan, to find new markets and therefore to propose new services, to consider complementary missions permitting to vary the way to finance the system and to make profit.

The second constraint rely on the considered level of system compatibility with previous generation: The problem is real at user terminal level, at gateway level, at satellite level, at network level, at waveform level, etc. In any case, whatever the considered compatibility level, the impact on the system design is very important and therefore important on the renewal strategy as we will see in section 4. On the other hand, because of the system frequency allocation (filling), the constellation owner is not inclined very much to make evolve the used band. And this will induce some issues concerning the second generation IOT to be carried out during the operations of the first generation.

The third and last major constraint is the way to answer to the switch issue. Is it preferable to switch suddenly and globally from the old to the new generation, or is it better to switch gradually the old constellation to the new one. As we will see in section 4, the choice is mostly driven by two points: mainly the “health” of the first generation constellation. Another element to do such a choice is the time-to-market as per the business plan, which allows to extrapolate when the new services must be available.

Another element is very significant to choose a renewal strategy: it is the number of satellites to be launched per launch and accordingly, the type of launcher to be used. The trade-off is here to find the good compromise between the number of launches, the price of a launch for a given launcher, the number of satellites per launch and the delivery time.

4. Possible replacement strategies

As presented in the previous section, several constraints of different natures have to be taken into account to build the renewal strategy of a telecommunication constellation. These constraints will be used to structure the replacement strategies description.

4.1. Evolution of the customer need

Generally, the data rate need, or at least the projections of the data rate need associated to the foreseen services to be implemented in the new generation of a constellation-based telecommunication system, is significantly higher than the previous generation one.

The impact of this constraint on both examples taken in this paper are quite similar on its principle, but nevertheless, some differences appear.

The feeder link (upward and downward link established between the satellite and a gateway, see figure 5) needs to support a higher throughput because generally considered new services include more high speed connections than the old ones. The current trends are to use IP based standards, and Internet based services are proposed accordingly. But when speaking about Internet based services, an implicit important notion must be underlined: the traffic is no more symmetrical, contrary to the voice telephony. So, for such services, the uplink data rate is higher than the downlink one. This not only imply to increase the throughput, but also to redesign the feeder link waveform in order to take into account such a dissymmetry. Moreover, because the distribution and the number of the gateways in both Globalstar and Iridium systems are very different, the increasing of the feeder link data rate is locally (Globalstar) or globally (Iridium) impacted by all the communications having to be routed to a given gateway.

The subscriber links (upward and downward links established between the satellite and Iridium subscribers reachable by the satellite at a given time, see figure 5) will need higher throughput as well. Again, the considered new services imply several types of high speed connections and the symmetry of the data rate is no more the baseline.

In Iridium case, there are other important links: the ISL (Inter-Satellites Links) allowing to connect a satellite to another one in the same orbital plane or in a neighbour one (see figure 5). Communications are routed from subscriber to the addressee whether he is an Iridium subscriber or not, through these ISLs (see figure 5). Consequently, it is obvious that if the subscriber links need higher data rate, the ISLs and the feeder links need higher data rate as well.

Moreover if the new considered services include secondary mission payload [6] the necessity to download the corresponding acquired data will increase the throughput increasing need.

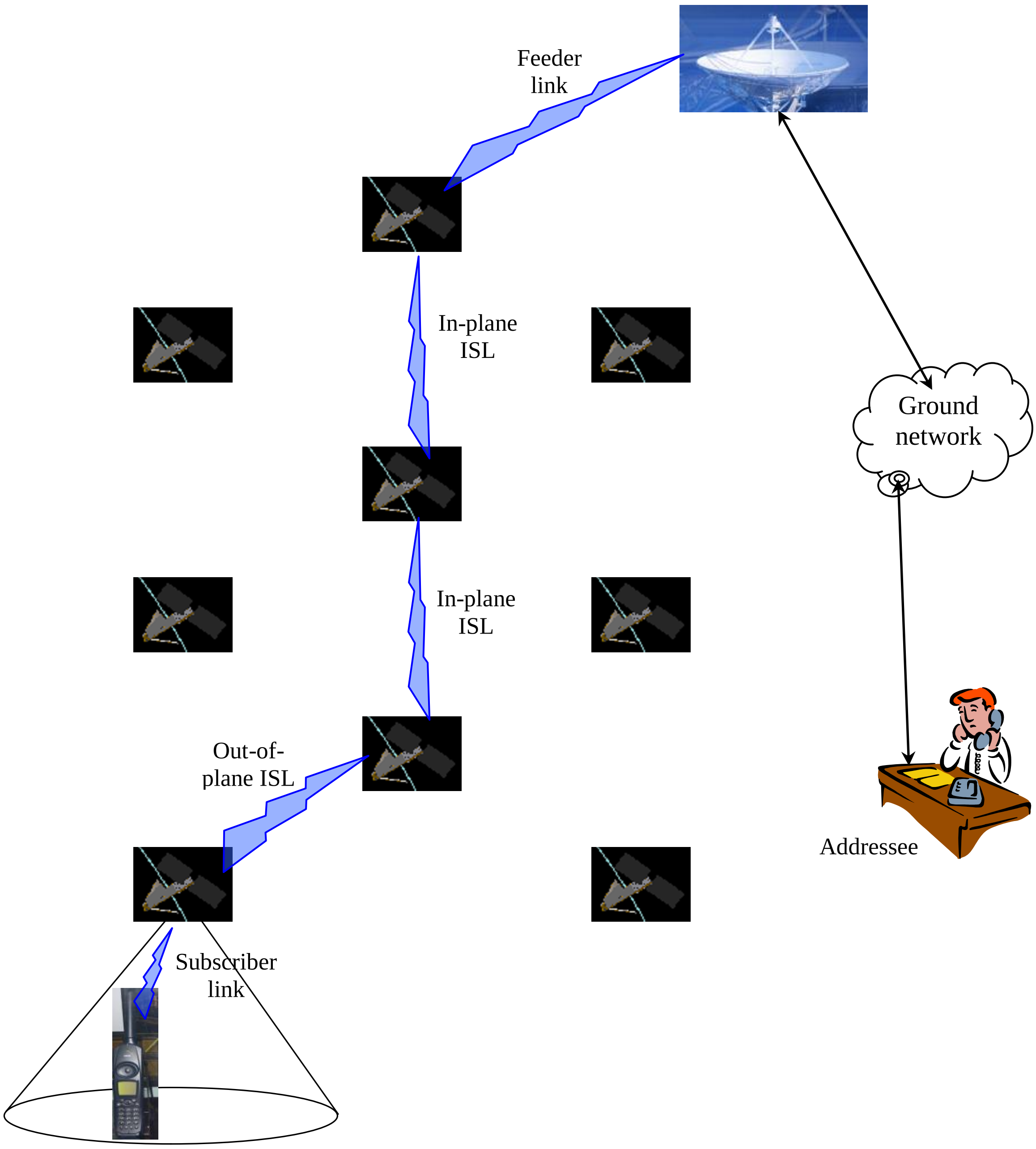


Figure 5: Routing through the Iridium system

4.2. Compatibility with previous generation

As already mentioned in section 3, the compatibility constraints can appear at subscriber's terminal level, at gateway level, at satellite level, at network level, at waveform level, etc. In any case, because it is not possible to remove all the old terminals at once, the satellites must ensure at least compatibility with them until their complete replacement by new generation of subscriber terminals. Of course new subscribers will get new terminals allowing to access to new services. But previously recorded subscribers will probably see their terminal renewed gradually, and the access to some of the new services (mainly high speed ones) will be delayed for them until that time.

Two solutions are possible, at satellite level, to manage the compatibility:

1. the choice is to make the new generation satellites not compatible with the system previous generation, except at subscriber terminal level. In such a case, the complete constellation deployment must occur, including IOT, before to switch-on the new system. The switch-off of the old generation system must be carried out "simultaneously".
2. the choice is to make the new generation satellites more or less compatible with the previous generation system. In such a case, the constellation deployment may take several forms according to the chosen system compatibility level.

   - The first form can be to replace "orbital plane by orbital plane". The main advantages are the very limited compatibility level to be ensured and the possibility to launch in only one plane at a time, but on one condition, to find adequate launchers. Currently, launchers capable to launch 6 satellites of Globalstar class are quite easy to find (5+1 satellites per plane for Globalstar constellation). It is more difficult for the 11+x satellites per plane of Iridium because this class of satellite allows launch by 8 or 9 satellites per launch on launchers giving the best "launch cost / launched mass" ratio. The adequacy between deployment duration and deployment cost will depend on acceptable drift duration and on the spare policy (see section 4.4).
   - The second form can be to replace "cluster of satellites by cluster of satellites" according to the "health" of the previous generation satellites. This option is a bit more complicated to manage in terms of deployment, because it generally imply drifts possibly long (up to 1 or 2 years) between the injection plane and the actual orbital plane. Nevertheless, this strategy allows to fit quite well to a possible degradation of the previous constellation during the deployment. However, a more important level of compatibility must be ensured, typically at ISL level in the case of Iridium.

In the above second case, the gateways can be used to support the interfaces between the satellites and the system infrastructure: the network, the access, the different protocols to be used. In the Iridium case, the gateways can also be used to perform the interfaces between two satellites of different generations using the feeder links. We can then envisage to use gateways to pass communications from one orbital plane to another avoiding the necessity to use across-plane ISL. This is particularly interesting when deploying such a constellation “plane by plane”, at least temporarily, because neighbour planes are of different generations for a while. By extrapolating such a solution, and because a gateway located northerly or southerly enough allows to see at least one satellite of each orbital plane at any moment, the switch of plane of a communication can be performed by such a gateway, avoiding finally the necessity to have across-plane ISL. This has also the advantage to simplify the payload allowing easily to implement redundancy of the along-plane ISL, and consequently to increase the reliability of the satellite while decreasing the cost.

4.3. Switch strategy

The switch strategy is directly impacted by the compatibility with previous generation considerations (see section 4.2).

If the first above presented solution is preferred, then the induced switch strategy is to switch from the former generation to the new one all at once. This is simpler to manage. The deployment is faster. But this strategy does not cope with the constellation “health” which could be a dramatic drawback is case of sudden degradation.

If the second above presented solution is preferred, whatever the sub-option, the deployment is more flexible (even more with the “cluster by cluster” replacement) allowing to choose the most “sick” orbital plane or at least the most “sick” cluster of satellites. But satellites and / or ground components are more complex than for the first solution. Besides, the deployment is generally longer than for the first above presented solution.

However, even if it does not suit very well the “health” of the previous constellation which appears as a major criterion, a global “all at once” switch could be a good approach for smaller constellations, or at least for constellations with a smaller number of planes compared to both constellations taken as examples.

Another point must be noticed. Depending on the number of satellites which are switched on at a time, the IOT must be performed at the operational altitude (if the number is rather big, i.e. for a complete orbital plane at once) or at a lower one (typically for a cluster). If IOT have to be done at operational altitude, it must be paid attention to the relative position in the orbital plane between old and new satellites, because if new satellites are too far from the old ones, it will produce coverage gaps (typically more than 1 minute) due to the unevenness in the satellites footprint. Generally, it can be managed by choosing a mean anomaly difference between new and old satellites as small as possible, but avoiding interferences on subscriber link, feeder link, but also ISL.

In the case of the global “all at once” switch strategy, new constellation planes can be deployed into existing orbital planes (here, the above remark about IOT is applicable) or in between the existing ones giving more margins to carry out the IOT (here, in case of across-plane ISL, one can easily find the mean anomalies of the new satellites avoiding such interferences).

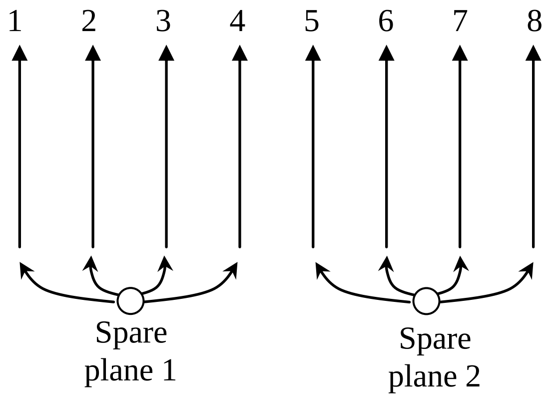
4.4. Spares policy

The spare can be envisaged directly in orbital planes at the operational altitude or at a lower altitude allowing to drift according to operational orbital planes. Generally, due to the drift duration between planes, and in order to suit the operational availability requirements, at least one spare is foreseen in the operational orbital plane which allows to replace any failing satellite of the plane in less than a week. We discard at this stage, spare launches by small number of satellites (less or equal to four) due to the price of the launch per satellite.

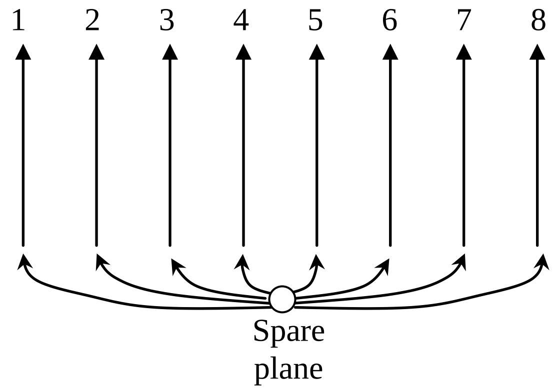
The spare policy is of course very impacted by the satellites reliability (quite different in Globalstar and Iridium cases, with consequently very different number of launched satellites, see section 2), but also by the launch strategy, and more precisely by the adequacy of the launchers capacity to the number of satellites per plane.

But whatever the situation in terms of adequacy of the launchers, the question is the number of spare planes: only one is easier to manage but implies longer replacement of a failed satellite, more than one is more difficult to manage in terms of launches but implies shorter replacement duration.

Such a question relies on the operational availability requirement, the reliability of the satellites, and the acceptable drift duration according to the other criteria. This drift duration depends on the difference of altitude and inclination between the spare plane orbit and the targeted operational orbital plane. The more the difference, the less the duration. And consequently, the dimensioning parameter is the ergols consumption which will limit the difference. Nevertheless, due to its higher operational altitude, Globalstar profits from a potential bigger difference between parking orbit and operational orbit, allowing to get shorter drift durations (some months) compared to Iridium (between ten months and one year).

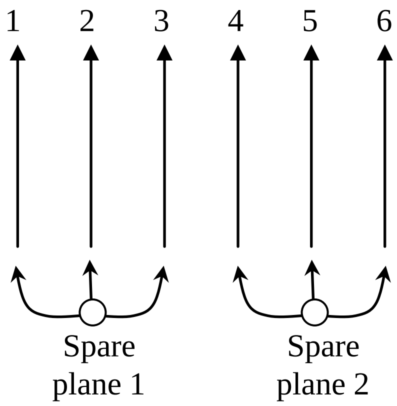


If the time to drift from one plane to its neighbour is considered as the Elementary Drift Time (EDT_1), then:
Max drift duration is1.5 EDT_1
Mean drift duration is 1 EDT_1
Min drift duration is 0.5 EDT_1

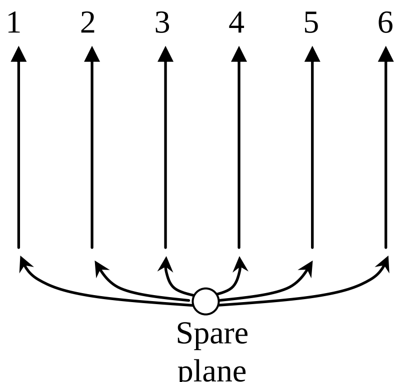


Max drift duration is 3.5 EDT_1
Mean drift duration is 2 EDT_1
Min drift duration is 0.5 EDT_1

Figure 6: Example of spare planes and the corresponding drift duration (Globalstar)



If the time to drift from one plane to its neighbour is considered as the Elementary Drift Time (EDT_2), then:
Max drift duration is1 EDT_2
Mean drift duration is 0.67 EDT_2
Min drift duration is some days



Max drift duration is 2.5 EDT_2
Mean drift duration is 1.5 EDT_2
Min drift duration is 0.5 EDT_2

Figure 7: Example of spare planes and the corresponding drift duration (Iridium)

In case of a deployment where the adequacy between number of satellites per orbital plane and the launchers capacity do not allow to inject on the nominal orbits the correct number of satellites, but a bigger number, the supplementary satellites must be drifted to the spare plane(s) before they "climb" to the operational orbit.

4.5 Synthesis of the replacement strategies

The synthesis is presented as a matrix giving sort of notation from "++" (the best) to "--" (the worst).

In case of unacceptable risk, the mark is "---".

Strategies / Criteria	"Global Constellation" Replacement	"Plane by Plane" Replacement	"Cluster by Cluster" Replacement
Cost	++	+	+
Complexity of the system transition	++	+	+
Duration of the constellation deployment	++	+	+
Compatibility with the previous generation	++	+	-
Service outage risks	---	+	++
Constellation and System AIV	++	+	-

Table 1: Synthesis of the replacement strategies assessment

The above synthesis seams applicable to both presented systems, even if, due to non-attendance of the ISL in the Globalstar system, the options "Plane by plane" and "Cluster by cluster" replacement are more similar than in the case of the Iridium system. Nevertheless, this synthesis is probably applicable also to other constellation-based telecommunication systems providing that the risk due to service outage is as stringent as in the two studied cases.

5. Conclusion

It shall be stressed that the reflections on replacement strategies of the two considered study cases do not preclude any other strategy to be implemented by the actual owner of both constellations. Indeed the choice of both constellations was only motivated by a will to illustrate the possibilities on concrete cases. The presented strategies can be applied to other satellite constellations in the telecommunication field. However, the renewal of such constellations is a good opportunity to put on the table the whole system and to re-design it. It could be the chance to re-assess the key-drivers which led to the design of the previous generation and then to challenge the constellation, not in terms of altitude (since it is imposed by the frequency allocation of the former generation) but in terms of:

- in- and out-of-plane distributions or in terms of number of satellites (it has been the case when the Globalstart constellation has been revised form 48 to 40 satellites in August 2003)
- the proposed services,
- the satellites type and capabilities,
- the ground components capabilities,
- the satellites and ground components reliability … and the corresponding spare policy, deduced of the assessment of the system operational availability,
- the way IOT will be carried out,
- …

But anyway, the replacement strategy is led by the "health" of the constellation and the financial aspects of the renewal, which appear as major key-drivers.

Due to the importance of these criteria, the "cluster by cluster" replacement strategy appear generally as the best compromise allowing the customer to not risk a disastrous service outage.

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