A Low Cost Self Consistent SETI Strategy, or Talking and Listening is Not Much More Expensive than Listening Alone

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Abstract

If all civilizations follow our current SETI strategy, then no contact will ever be made though the galaxy may be teeming with life. Everyone will be listening, and no one will be transmitting. Therefore we should at least think about when, where and why we should transmit, and the cost of doing so. We will call a strategy *consistent* if it always results in contact between technical civilizations if both follow the strategy, both live long enough, and they are close enough. For obvious reasons, any consistent strategy involves both transmitting and receiving. Our current strategy, such as it is, is basically to listen only for now. At some indetermine future time, if nothing is heard, we *may* establish a beacon. An alternative strategy is to mimic what we do naturally on the receiving end - send beacons to the nearby stars now, and gradually extend our range. A simple version of this strategy guarantees contact with civilizations D light years away in no more than $6D$ years. A possible implementation of this strategy shows that even with current technology the cost of such a strategy is surprisingly low, and could easily be afforded by institutions the size of the current SETI institute.

1 Introduction

If all civilizations follow our current SETI strategy, then no contact will ever be made though the galaxy may be teeming with life. Everyone will be listening, and no one will be transmitting. Therefore we should at least think about when, where and why we should transmit, and the cost of doing so.

Of course, we are transmitting already (leakage). Is this enough? Probably not - we are a very long way from being able to detect leakage, even from nearby stars. The gap is large - perhaps 5 orders of magnitude.

So why do we not also transmit as well as receive? Deciding to transmit involves a range of tradeoffs and decisions, some of which are difficult to quantify.

- There are many philosophical issues over whether transmitting at all is a good idea (aliens might be unfriendly)
- What should we say, if we do transmit?
- A specific frequency must be chosen, unlike receiving where we can cover a range of frequencies.
- Higher EIRPs cost more, but are beneficial for two reasons. First, for any given sensitivity, more civilizations can see a stronger beacon. Second, transmitted EIRP affects the effective value of L. We can currently detect 1 TW transmitters. Our ability to receive is

(historically) increasing by a factor of 10 every X years. Depending on your estimates of L, the different between 1 MW and 1 GW may be a significant fraction of L.

- Cost vs time. Different beacon scheme may involve a big one time expense, or a slow steady expenditure, or an expenditure that varies with time.
- The assumed lifetime of a technical civilization, L, affects the strategy. Any strategy that involves waiting, then transmitting later, has a risk that transmitting may never happen at all.
- There is a benefit to others (making their job easier) and a possible benefit to us (earlier contact) and an obvious cost. How do we weight these?

2 A consistent strategy

We will call a strategy *consistent* if it always results in contact between technical civilizations if both follow the strategy, both live long enough, and they are close enough. All consistent strategies must involve both receiving and transmitting, since two receive only or transmit only civilizations will not connect. Also a consistent strategy must have the transmitter and receiver on the same frequency and the receiver must be sensitive to the modulation type the transmitter is sending.

For a given sensitivity and power, a strategy is consistent out to some distance. Beyond that, though the transmitter and receiver share a common frequency, and both are pointed (if pointing is used) at each other, the signal is simply too weak. The distance D for an equivalent isotropic transmitted power P and sensitivity S is:

$$D = \sqrt{\frac{P}{4\pi S}}$$

Also, for contact to be made, the frequency and modulation type need to be common. CW modulation seems to be the choice in the radio bands, and for reasons that seem to be universal. It is easy to detect, maximizes sensitivity, and does not occur naturally. The frequency is a much tougher call. Various 'magic' frequencies (or bands of frequencies) have been suggested, but the fact that there are various suggestions implies this is not universal. Since receiving a wide range of frequencies is easier than transmitting over a wide range, a reasonable compromise is to receive on all plausible frequencies, and transmit on whatever is most technically convenient.

Our current strategy is not consistent out to any useful distance. We are constantly transmitting (leakage) at about the 10 MW level (TV carriers) and our current sensitivity is about $8 \cdot 10^{-27}$ w/m^2. This gives a consistent range of only one light year, a distance that contains no stars at all. Furthermore our strongest leakage is at different frequencies than our most sensitive searches. We have no plans for any search sensitive enough to detect leakage similar to our own. We are assuming that some über-civilization will be sending a beacon, but we ourselves have no plan to do so.

There are basically two ways to make a consistent strategy with an improved distance. We could plan for searches good enough to detect leakage, or we can plan to eventually transmit. The improved sensitivity approach is difficult and expensive. We are already using the largest and most expensive radio telescopes in the world, and sensitivity is approaching the limit set by the cosmic background radiation. The only possibility here is to use still larger antennas, an expensive proposition, and one big enough to detect leakage is exceedingly expensive and vary large physically (perhaps 10^5) square kilometers. At some point it will be cheaper to transmit, if we wish to be consistent.

The Cyclops report proposed in broad outline a consistent strategy. It proposed that after we have examined all the stars where we have enough sensitivity to detect a 1 GW EIRP transmitter, if we find nothing then we will establish a 1 GW omni-directional transmitter ourselves. This strategy is consistent to about 100 light years, assuming a Cyclops array of 1000 100 meter radio telescopes. The power for the transmitter alone (at today's prices) would cost about $700,000,000 (US) per year, far beyond the resources of organizations like the SETI institute. If we choose to follow this strategy, therefore, we must hope that alien civilizations are more advanced, or more benevolent, or both. Furthermore there is the risk that we will go extinct before beginning to transmit, in which case the strategy is not really consistent.

The Cyclops omni-directional beacon spends a lot of power transmitting in all directions, most of which have no stars. This suggests a cheaper consistent strategy - just transmit to those stars that are consistent with your transmitter power and sensitivity. In the Cyclops case, only 1000 stars are within their consistent distance. By transmitting to these stars alone, the power needed (and hence the cost) can drop by many orders of magnitude (or, more likely, the EIRP can be increased and the consistent distance increased, while still for much less cost). This is entirely possible with modern phased array transmitter technology.

Cyclops proposed that we examine the nearby stars first, then expand the array and examine stars further away if no positive result is found. We can do the exactly the same when transmitting to create a consistent strategy. We could expand our transmitter as money permits, or we could stick to a pre-determined schedule. (After all, our leakage reaches different stars on a pre-determined schedule, determined by the speed of light.)

Many schedules and consistent strategies that follow this outline are possible - here is a simple example. For all stars, first measure the distance D (in light years) from us. Look at this star at least every D years and reply immediately if we see something. If we see nothing $3D$ years after our leakage started, start to transmit a signal that direction that we ourselves could see.

For the purpose of this argument, we will set the date when our leakage was significant to 1960. The exact date is of little importance.

If two civilizations D light years apart both use this strategy, the longest possible delay is $6D$ years until contact is established (starting from the time when the latter civilization achieves radio competence). Let us suppose we are this latter civilization. In D years from 1960, our leakage will reach the other civilization. In D more years they would have looked once, and started to reply if they saw the signal. After $3D$ years we see no reply, and start to send. Starting at $4D$ years, their system is bathed with a strong signal. By $5D$ years they will have looked once, and seen a signal even if their technology is no better than ours. By $6D$ years we will have received their reply.

We will see below that this yields a consistent distance of 10 times Cyclops, containing about a thousand times more stars, for a small fraction of the cost.

3 Cost

The cost of an incremental, pincushion beacon strategy is surprisingly low.

We use a few simple technical observations. First, if we have M transmitters of power P_0, and we can adjust the phase of each transmitter, we can transmit with an EIRP of M^2P_0 in a direction of our choosing. (This will reduce the power in other directions, so the total power is still MP_0.) This power can be divided into as many beams as we want, provided the number of beams is less than the number of elements. Physically, the antennas must be placed at least 0.5 wavelength apart, and about 0.6-0.7 λ is more usual since it allows the beam to be steered off axis without significant losses. Finally, since we need real time control of the phase of each element, each beam can be doppler compensated for little or no additional cost.

Currently, we can build a low power (about 10 mw) X band phase controllable microwave transmitter and antenna for about 20 cents[1]

Locally the number S of stars within a radius R light years is roughly

$$S(R) \approx R^3/1000, R <= 1000 \tag{1}$$

since there are about 1M stars within 1000 light years, and they are roughly isotropically distributed. Above this distance we have used up the thickness of the galaxy, and are expanding through the disk, so the number of stars within a given distance grows only like R^2. Then we have roughly

$$S(R) \approx R^2, R >= 1000$$

for distances up to the galactic center. There the number grows again, but this is far beyond the practical horizon of this paper.

Let the number of stars we are transmitting to in the year t be $N(t)$, where t is in years, and measured from our time of first serious leakage production. Assuming we are transmitting with an EIRP of E_0 watts to each of the stars, the total EIRP is $E_0 N(t)$. The number M of transmitters of power P_0 required to produce this EIRP is

$$M = \sqrt{\frac{E_0 N(t)}{P_0}} = \sqrt{\frac{E_0}{P_0}} \sqrt{N(t)} \tag{2}$$

So the total cost C up to year t, assuming each transmitter costs C_0, is simply

$$C = C_0 M$$

and the total power P in the year t is

$$P = P_0 M$$

The additional cost for transmitters each year is just the derivative of the total cost, or

$$\frac{\mathrm{d}C}{\mathrm{d}t}$$

3.1 A Numerical Example

When we plug in the numbers, the cost of such a strategy is surprisingly small. Assume we want a strategy consistent out to 1000 light years, encompassing roughly a million stars. Assuming an SKA like facility with one order of magnitude better sensitivity than the current state of the art, this implies a transmitter EIRP of 10^{12} watts. For the next 3000 years we are on the isotropic part of the star count curve, so

$$N(t) = S(t/3) = t^3/27000$$

and assuming $E_0 = 10^{12}$ watts, and transmitters with $P_0 = 10$ mw, this simplifies to

$$M \approx 61000\ t^{3/2}$$

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[1] This particular figure is for X band, and not precisely true. If fact, we can build 100 of these for \$20, using a single chip and a PC board with printed antennas. For our purposes having transmitters come in groups of 100 makes little difference, since large numbers are required, as we will see.

The dollar cost C of this many transmitters, assuming the $C_0 = \$0.20$ cost per transmitters of today's technology, is then

$$C \approx 12200\ t^{3/2} \text{ dollars}$$

and the total amount of power required is

$$P \approx 610\ t^{3/2} \text{ watts}$$

Suppose we wait 100 years to start, in the year 2060. The first transmitter, to all stars within 33 light years, costs only \$12M, less than the Allen Telescope Array. Running it takes 610 KW of power, costing \$430,000 per year in power at \$0.08 dollars/KWh. Then suppose each year the appropriate number of new elements are added to the transmitter to reach the additional stars added that year. The incremental cost for the additional transmitter modules is

$$\frac{\mathrm{d}C}{\mathrm{d}t} \approx\ 18300\sqrt{t}\ \text{ dollars/year}$$

or only \$183,000 per year at $t = 100$ years. This is only a small fraction of the budget of the SETI institute even today, and *this is what we could do with today's technology. It will be even easier to transmit in the future.* And this strategy can be kept up for a long time - at 1000 years, it's only up to \$580K per year of additional transmitters, and a total transmitter power of 19 MW. Note that compared to the Cyclops 1 GW omni-directional transmitter, this is 1000 times the EIRP for 1/50 source power, and about 1000 times more stars illuminated with a power that we ourselves could detect. Furthermore, each beam can be completely Doppler corrected for both the rotation of the Earth and the motion of the earth in its orbit, which is not possible with an omnidirectional transmitter.

4 Technical improvements

With a phased array, we can also vary the power sent to each system. This saves energy since a lesser EIRP will give the same received power for closer systems. Assuming an SKA for receiving, for example, we need 10^{12} watts for the stars 1000 light years away. A star 100 light years away needs only 10^{10} watts. The savings from this are not dramatic since most of the stars are near the maximum distance, but it can be useful.

To compute the savings this gives, we note that the total power required is proportional to the integral over a sphere, times a weighting factor that describes how the power varies with distance. Without loss of generality we can set the maximum radius to 1, and the power at maximum radius to 1, since we are only concerned with the relative total power of the two schemes. For the constant power scheme this gives:

$$\int_0^1 4\pi r^2\ \cdot 1\ \mathrm{d}r = 4/3\pi \tag{3}$$

The variable power scheme has the same integral, but now weighted by r^2

$$\int_0^1 4\pi r^2\ \cdot r^2\ \mathrm{d}r = 4/5\pi \tag{4}$$

Taking the ratio between (3) and (4) the variable power scheme requires 3/5, or 60%, of the total power of the constant power scheme.

4.1 Shorter Wavelengths

We can do still better by moving to a shorter wavelength. This gives more antennas per PC board area, which is one of the main costs. We are dependent on a weird part of Moore's law - the number of pins per dollar. The computation itself is already so cheap that the cost of the pin to get the signal to the antenna is the limiting factor.

In the long run, imagine an array of tiny (1 microwatt) transmitters. At 34 GHz, there are about 6400 per square meter of them. A 12.5 km on a side array has 10^{12} of such transmitters, allowing a 10^{12} watt beacon to each of 10^{6} stars. The total power for such an array is 10^{6} watts, for a power of only 1 watt per star! (This assumes we can compute the desired phase for each transmitter with less energy than the transmitter itself radiates. It is clear we can do this for a 10 mw transmitter; for a 1 μw transmitter it is not so clear without further study). Another possible problem with such a physically large array is that the beam may be too small to hit the whole reasonable target area of the nearby stars. A rough calculation shows that the array used in the above examples would have this problem. With 10^{12} transmitters on 0.6 λ spacing, the array is about 600,000 wavelengths across. Therefore the target beam will not spread to 10 AU across until it has traveled about 100 light years. Closer targets will need to use only a subset of the transmitters. The array of 10 mw transmitters does not have this problem. Even at the full extent of $3.2 \cdot 10^{9}$ transmitters, it's only about 34,000 λ on a side, and even at 10 light years away the beam is roughly 20 AU in diameter.

The same technology would allow an individual to set up a private beacon that could be run under as an amateur radio operation. It would be 400 meters on a side, have 10^{9} transmitters totaling 1 KW, and an EIRP of 1 TW.

Note the using this general idea, beacons are cheaper the higher their frequency (since, in our technology, a PC board of fixed size is approximately fixed cost no matter what is etched on it. Since the gain is highest with the most antennas, the total cost is lowest when the greatest possible number of antennas is crammed onto one board. This is a likely concern whenever elements are basically 'printed' as opposed to manufactured. Until (and if) nanotechnology becomes widespread, printing technologies are the cheapest known, so this preference for high frequencies may apply to aliens as well.

There are two limits to this strategy - atmospheric transparency and quantum noise. Quantum noise starts to hurt receivers, doubling the noise at about 50 GHz and rising linearly with frequency thereafter. Atmospheric transparency limits earthbound transmitters to about the 30-35 GHz.

5 Conclusions and Implications

An interesting implication is that if we are going to look for beacons and not leakage, we should be doing so at much higher frequencies than we currently examine, since it looks easier to build beacons at higher frequencies. On the other hand it should not be necessary to look for drifting beacons - any beacon of the power we can see is probably built with phased array technology, and can be assumed to be doppler corrected with very little extra effort by the transmitting civilization.

Next, looking for a strong (about 10^{12} W EIRP) beacon is not unreasonable. An omnidirectional facility of this output would indeed take a civilization that is considerably more advanced (at least economically) than the Earth, since such a beacon takes a significant fraction of the entire Earth's electrical output. However, phased array technology is both cheaper and much more energy efficient, to the point where a private institution the size of the SETI institute could easily afford to build such a facility.

In fact, transmitting is sufficiently cheap, even with today's technology, that we might want to consider doing so ourselves if searches reveal nothing, and assuming the ethical issues of transmission can be dealt with. This way we could at least say our strategy is consistent. In fact, it might reassure donors that there is a concrete plan. The plan might look like this:

> First, expand our searches to cover all plausible radio frequencies, perhaps 1-40 GHz. If we hear nothing by 2060, then we start to transmit, first to local stars and gradually increasing in range. The beams are strong enough that we ourselves would have detected it with our existing searches. Here is a design that we could build today; a better one will probably be available by then, but it can be at least this good....

Finally, we should assume, should we receive anything, that it may not be representative of the civilization that sent it. It might not be from their equivalent of a world or even national government, sent only after a strong concensus had been reached. Instead, it could be from a small private group with a strong incentive to transmit. A good analogy might be missionaries on earth. What we might see, as an isolated outpost, might be those most motivated to spread their views, not those that are most commonly held. This is because transmitting is cheap enough for small private groups to do individually, rather than by consensus of a transmitting civilization.