June, 2002

The Ultimate Hacker: SETI signals may need to be decontaminated[1]

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Introduction

Biological contamination from space samples is a remote but accepted possibility[1]. Signals received by searches for extraterrestrial intelligence (SETI) could also contain harmful information in the spirit of a computer virus. There have been many searches for extraterrestrial intelligence (ETI) since the recognition of the possibility of detecting ETI signals by Cocconi and Morrison[2] four decades ago. Some argue that information in an extraterrestrial signal could not attack a terrestrial computer because the computer logic and code is idiosyncratic and constitutes an impenetrable firewall. Suggestions are given on how to probe these arguments. Measures for decontaminating SETI signals are proposed. The need for modification of the SETI detection protocol[3] is suggested.

Background

The potential for biological contamination by material from space has been recognized since the manned lunar program. Is there a similar potential for contamination in an ETI search? Surprisingly, the possibility of a malevolent signal has rarely been discussed in the SETI literature (see, however, the comments of M. Ryle, G. Wald, T. Kuiper, M. Morris and others[4]).

Concern for the remote possibility of biological contamination led to the establishment of a protocol for decontaminating material returning from space. The International Committee on Space Research (COSPAR) developed this protocol through meetings involving international space bodies and the United Nations. Concern about biological contamination is rooted in many experiences where new biological species were introduced to another ecology and then seriously impacted the environment. The SETI field does have a protocol to follow if a signal is discovered. This is mainly intended to avoid public problems if a signal is announced prematurely.

Many searches have been carried our for ETI signals[5]. These include radio[6] and optical searches[7]. ETI searches are now approaching a level where a substantial fraction of sun-like stars out to several hundred light years have been monitored at least once.

[1] Poster prepared for International Astronomical Union Symposium 213, "Bioastronomy 2002: Life Among the Stars", Great Barrier Reef, Australia, July 8-12, 2002.

SETI can be criticized on several grounds. One view is that the occurrence of intelligent systems capable of generating signals is rare in the galaxy[8] based partly on the perceived rarity of higher intelligence in bio-systems. However, it is also conceivable that in some cases the evolution of intelligence could have undergone a phase change where it moved from biological to computer intelligence. Further, this process could undergo an inflationary increase if some generalized Moore's law process set in, as it has for computer chips, lasers, and accelerators on earth. It is easy to envision that signaling sources will be many orders of magnitude more intelligent than we are. A second criticism is that the searches are not extended enough to have a chance of finding a signal. They search individual stars or sky regions for short times and the galactic reach is modest. While there is merit to these criticisms there has recently been significant progress in extending search capabilities. At some point a search may be successful.

Recently interest in ETI searches has quickened due to discoveries of many stars[9] with planetary systems[10]. A thousand or so sun-like stars within 100 light years (ly) have now been searched for planets. At least eight percent have Jupiter-sized planets[11]. This is a lower limit since the Doppler shift measurements used for most of the discoveries limits detection to Jupiter-scale planets. The actual fraction of stars with planets may be substantially higher so that a sizeable fraction of sun-like stars could have planets. New information is emerging rapidly so that it is becoming increasingly feasible to direct searches at favorable SETI candidates.

SETI Signals

It is useful to distinguish two types of ETI signals, beacons and messages. A beacon would be a lighthouse intended to call attention to the source but with little information content. A message carries information. Since a beacon typically would not carry much information it could use a narrower frequency spectrum. It could also operate at lower power for the same transmission distance because the detector could use a higher Q circuit. The beacon might contain a short message directing the signal receiver to a different frequency for a message signal. A beacon reveals the location of the source and the planetary orbit characteristics.

For a noisy radio link, the Shannon limit for the channel capacity in bits/s is:

$$C \leq \frac{B}{\ln 2} \ln\left(1 + \frac{P_r}{kT_N B}\right) \qquad (1)$$

where B is the bandwidth, T_N is the receiver noise temperature, and k is Boltzmann's constant[12]. P_r is the power received by the earth antenna and is given by the Friis transmission formula:

$$P_r = P_t \frac{\pi^2}{16} \frac{D_t^2 D_r^2}{\lambda^2 R^2} \qquad (2)$$

where P_t is the transmitter power, D_t and D_r are the effective diameters of the transmitting and receiving antennas, λ is the wavelength, and R is the distance between the transmitter and receiver. Leigh shows that for a low signal to noise ratio the maximum channel capacity is:

$$C_m \approx \frac{P_r}{kT_N \ln 2} \qquad (3)$$

In this case the channel capacity depends on the power received but not the bandwidth. With a 10 GHz carrier (λ = 3 cm) a 1000 kW signal at 50 ly could transmit more than 10 Kbytes/s assuming Arecibo-sized antennas with a receiver noise temperature of 10 degrees K and a 1% bit error rate. A 1 Gbyte program or computer encyclopedia would take about a day to transmit and cost $2400 assuming a power cost of 10¢/kWH. This is only an order of magnitude more expensive than buying software on a CCD. The dispersion of the interstellar medium limits the transmission bandwidth. Following Leigh the upper limit on the bandwidth for a 1000 ly path is 3.5 MHz, quite sufficient for a 10 Kbyte/s transmission rate at 50 ly.

Optical and near optical SETI have some features that are different than radio SETI[13]. The spread of a laser beam may be too small to fully illuminate planets several AU from a star. The diameter of the Airy disk is $2.44\lambda/D_t$. For a laser wavelength of 1.019 µm, a lens with D_t = 1 m, and R = 50 ly the disk is 8 AU, on the small side for a sun-like planetary system. The laser must be pointed with great care and lead the star to account for stellar motion during the signal transit. Indeed, not only the transverse coordinates and velocities but also R must be known accurately. The requirements are challenging but not outside of potential earth-based technology. Beyond 1000 light years signals in the visible suffer significantly from extinction. Background effects are less important. A nanosecond megajoule laser pulse easily outshines the sun.

Horowitz and his colleagues have developed a scenario for optical transmission using a laser near a distant star[14]. They posit a laser similar to the proposed 10 Hz Lawrence Livermore National Laboratory Helios device signaling through 1-10 m optical elements and being detected with coincident photomultipliers. The directivity or gain of a transmitting lens or mirror is:

$$g_t = \pi^2 \frac{D_t^2}{\lambda^2} \qquad (4)$$

The photon fraction at the detector is the gain times the detector area divided by $4\pi R^2$. The number of detected photo-electrons is:

$$N_e = \frac{f\pi^2 D_t^2 D_r^2 E_p 10^{-4R/5R_E}}{16\lambda R^2 hc} \qquad (5)$$

where f is the photon conversion efficiency, E_p is the energy of the laser pulse, and R_E is the extinction distance. For Helios E_p = 4.7 MJ at λ = 1.019 μm. If R = 50 ly and f is 0.2, N_e is about 1300 electrons per laser pulse for D_t = 1 m and D_r =10 m (a Keck equivalent).

To estimate the signal transmission rate recall that the error on the electron signal is $\sqrt{N_e}$ or about 36 electrons. If the pulse height is parsed into 3 σ bins the amplitude can be described with about 4 bits to give a transmission rate of 40 bits/s. Pulse time modulation could carry more information. If every 10th pulse served as a time and amplitude mark (the equivalent of a carrier signal) the other nine pulses might be modulated in time by up to 50 ms (50% of the pulse spacing). Dividing the interval into 10 ns bins (about 3 sigma equivalent for the Horowitz apparatus) gives $5*10^6$ intervals, which can be used to represent a 23 bit number. The transmission rate is 270 bits/s using time and amplitude modulation. The radio transmission rate might be reached with an efficient transmission algorithm, a Keck-sized transmitting element, and ten times faster detectors. With a 100% wall plug to laser efficiency (at least 4 orders of magnitude better than many lasers currently deliver) the cost per bit for laser transmission in this example is 10^4 times higher than radio transmission.

Townes[15] and Lampton[16] have explored the relationship between the transmission rates for optical and radio signals in some detail. Lampton uses the Friss formula (equation 2) to get the transmission energy/bit. The relative fraction of transmitted energy for radio vs optical is then:

$$f_{R/O} = \left[\frac{\lambda_R D_{rO} D_{tO}}{\lambda_O D_{rR} D_{tR}} \right]^2 \frac{E_{rR}}{E_{rO}} \qquad (6)$$

where E is the energy/bit and the index R indicates radio and O optical. For Lampton's assumptions (larger transmitting element, smaller signal to noise, lower radio frequency) the energy or cost per laser bit is 10^{-3} of a radio bit. All of the difference between the two perspectives is explained by the underlying choices. Considering the energy cost per bit diminishes the significance of repetition rate, a factor where contemporary high power lasers fall short in comparison to microwaves.

Based on current earth technology as sketched here optical signals might serve for beacons between stars less than 1000 ly apart because of background considerations but they seem less likely for long message transmission. Of course lasers are still in a Moore's law expansion phase while radio technology is rather static. Transmitting civilizations would undoubtedly be more advanced than contemporary earth technology. In summary, both radio and optical transmissions can be economical and the possibility must be considered that either may contain dangerous material.

Why be concerned about a SETI signal?

Why should one be concerned about a potentially dangerous ETI signal? The appearance of computer viruses has been a surprising development in the emergence of heavy computer use. Viruses are characteristically introduced into operating system programs maliciously and can have serious consequences.

It is difficult to posit the motivation behind a signal arriving from space. Most SETI investigators assume the signal is a beacon beckoning to other stars and welcoming contact. A biological metaphor for this perspective is a sexual mating signal. In fact, many biological systems seem intent on sending no signals of their presence and doing their best to blend into the background. There are many other biological metaphors where signals are used as lures.

Parenthetically several signal envelopes are now moving out from earth that could be detected with sophisticated instruments. These include television signals (on the order of sixty years), radio (100 years), and possibly atmospheric signatures of large-scale fuel use. These signals are an open announcement of our presence. Sullivan, Brown, and Wetherill looked at this possibility in some detail including investigations using reflected signals off the moon[17]. Tarter notes TV transmitters on earth can be detected one light year away with contemporary technology. An intelligent system on a star fifty light years away detecting earth's first radio signals could have broadcast a return signal that would now be reaching earth. There are approximately 400 stars within this fifty light year sphere.

An illustration of a dangerous SETI signal is something like the "drink me" bottle in Alice in Wonderland. The signal could consist of one easily translated "beacon" directing the use of attached code to expand a compressed data string, analogous to a computer installation disc with a startup icon. Initiating the startup would install software that could take over the computer it resided in. A variant would be to give instructions for building a hardware translator.

The concern, then, is that a signal could lead to unexpected and possibly harmful consequences. Hopefully no one receiving an obvious "drink me" message would act until they had considered the consequences. A more insidious possibility is a steganographic or "hidden writing" signal without an obvious underlying message that could still install and operate software on a computer.

Several steps are required to turn a message into operating code. The raw signal in memory must bootstrap itself to the status of an operating program. Then that program must untangle the inner workings of the host computer and learn how to translate its own unpacking program into the local computer language.

SETI signals on an earth computer

Is it possible for a SETI signal to operate like a computer virus on an earth computer? This is almost a trite question for someone who has used a computer on the Internet where viruses routinely attack computers with devastating effects. Some computer experts have a different view concerning the possibility of a SETI computer virus. The argument goes as follows. Viruses rely on known features of the operating system to find a portal into a computer. Once in the computer the virus must employ the local code. Typically the code for the earth computer instructions is arbitrary, much like human languages. Experts argue that even with a sophisticated understanding of computers the barrier of the idiosyncratic language is an unbreakable firewall. Another argument is that the download process seriously scrambles the signal content. This is particularly true for radio SETI where fast Fourier transforms are used. Finally, ETI code would probably be vastly more complicated and not adapted to earth's primitive computing environment. For example, the whole process might be more in the spirit of visual processing rather than our largely linear model. In this picture, the SETI hacker message fails because it expects more sophistication.

Some of these arguments can be investigated empirically. Two challenges are to find a stored data array that can bootstrap into an operating program for an existing operating system and to devise a program that can determine the operating instructions in an unfamiliar system. It might be possible to bootstrap by interlacing the SETI data with strings of simple digits followed by the address for the translation code. The strategy would be to hope the main code failed once in a way where the program counter passed an appropriate jump instruction. A variant might be to use a virus in a high-level (alien) language and attach it to a data file. Some people would not want to wager that something like this could not be done.

Decontaminating SETI signals

If a SETI signal is potentially dangerous steps should be taken to decontaminate it and surround it with a firewall. The problem outlined above suggests several prophylactic measures for SETI signals. These largely follow conventional practices for computer security[18]. Data storage for downloaded SETI signals should be kept on machines isolated from the analysis task. SETI signals could be fragmented into small packets and kept apart except under controlled conditions. Data could be quarantined on isolated computers and watched to see if aberrant behavior arose. Check sums and program integrity checks should be carried out routinely on computers processing SETI information. However even earth-grown computer viruses have been known to use camouflages to subvert such checks. Machines running SETI translation could use hardware where the operating codes were essentially one-time ciphers that could not be broken. Finally, beacons with no signal content can be handled without as much care as information-loaded signals. Most searches concentrate on narrow, beacon-like signals that are effectively demodulated.

Interestingly, item 6 of the present SETI signal detection protocol could exacerbate any negative consequences of a SETI signal. Item 6 reads *"… data bearing on the evidence of extraterrestrial intelligence should be recorded and stored permanently to the greatest extent feasible and practicable, in a form that will make it available for further analysis and interpretation. These recordings should be made available to the international institutions listed above and to members of the scientific community for further objective analysis and interpretation.*" If there is a concern about potential negative effects from SETI signals this item should be modified to control distribution until the signal is thoroughly understood and sterilized.

SETI@Home[19] is an illustration of a SETI analysis process that is not antiseptic. Hundred second long, 20 kbps antenna downloads (about 0.25 Mbyte) from Arecibo are sent to individual computers for analysis using SETI@Home software. The software performs many different computations including fast Fourier transforms. While this process does fragment data into small packets it spreads the data over more than a million unsecured computers. Interestingly, SETI@Home has been successfully hacked.

If there is a potential SETI signal problem it deserves the same consideration given to the possibility of biological contamination from space. It needs the attention of computer experts including security specialists and people with a long-range historical perspective on where computing might be going. The views of cryptographers, archaeologists, and the biological contamination community should also be useful.

Cocconi and Morrison close their ground-breaking SETI article with the comment "*The reader may seek to consign these speculations wholly to the domain of science-fiction. We submit rather, that the foregoing line of argument demonstrates that the presence of interstellar signals are entirely consistent with all we now know…We therefore feel that a discriminating search for signals deserves a considerable effort. The probability of success is difficult to estimate; but if we never search the chance of success is zero.*" This could be paraphrased for the possibility of a malevolent SETI signal as *the probability of a contaminated SETI signal is difficult to estimate; but if we never consider it the chance of infection is not zero.*

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