Server Sky - Information Farming in Space

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***Abstract*—Server sky is a proposal for vast constellations of tiny space satellites, computing and exchanging information directly with cell towers serving customers, students, researchers, and entrepreneurs in the developing world. Paper-thin 5 gram "thinsats" will power processors, memory, and 60/70 GHz radios with 4 watts of space solar power. 7842 thinsat arrays produce sub-kilometer ground spots. Highly redundant, cryptographically secure, radiation-resistant thinsats will be recycled at end-of-life.**

***Index Terms*—Space Technology; Integrated Circuits; Solar Energy; Internet; Globalization**

I. Introduction

> *"A telephone in every village ... I believe it is a realistic and desirable goal by the year 2000. It can be achieved now that millions of kilometers of increasingly scarce copper wire can be replaced by a handful of satellites in stationary orbit."* — Sir Arthur C. Clarke, 1983 [1]

Billions of valuable minds are trapped in poverty and isolation in the developing world, performing manual labor in want and squalor, rather than participating in the design and deployment of an abundant and efficient global civilization.

The developed world is enabled by the consumption of massive quantities of energy and minerals, much gathered in the developing world. Fortunately, increased efficiency enabled by technological innovation has reduced resource consumption per unit of economic output; for example, steel production in the United States consumed 67 MJ/kg of energy in 1950, reduced to 15 MJ/kg in 2005. The annual power consumption of refrigerators made with that steel dropped from 1900 kWh to 500 kWh between 1972 and 2009. Knowledge can reduce physical consumption [2].

The changing product mix reduces energy and resource consumption as well. Production and use of a 112 gram iPhone 5 creates 75 kg of CO_2 over a three year lifetime [3] and connects to the planet, while an 875 kg, 4.9 liter/ 100 km Smart Car produces 75 kg of CO_2 traveling only 650 kilometers [4]. Telework, online shopping, and online social networking can save thousands of kilometers and hundreds of hours of driving per year in a society already centered on the automobile.

New information-centric societies optimized for personal electronics and global networking can develop faster, cheaper, and greener without replicating the developed world's consumption of materials, energy, and distance. Innovation is inspired, or hindered, by everyday experience. Information-centric cultures can invent new systems for living unimaginable in cultures chained to steel and carbon. Info-cultures will have the key to the future, which will open the door to the solar system.

Information can be expensive. Data centers consume more than 10 GW in the United States, almost 3% of US electrical power [5]. Most of this power is spent on voltage transformation and cooling; less than 40% of the incoming grid power reaches the computing load [6].

400 000 diesel-generator-powered cell towers provide rural India with basic telephone service, connected by microwave links [7]. Basic communication bypasses middlemen and increases rural income, while bringing education, rule of law, and political power to remote and vulnerable communities [8]. Broadband internet offers more, but requires more power and bandwidth.

Google manufactures information from energy, producing \$20 of revenue per kilowatt-hour of wholesale electricity. Google's "green" slogan is "renewable energy is better than carbon" (RE>C) but they are enormously wealthy because information is better than energy (I>E). Google sells their products worldwide, at the speed of light, because information is easier to move than energy. Much of Google's workforce was born in the developing world [9], and many more could work near their birthplaces with inexpensive and reliable high bandwidth infrastructure.

While computation efficiency is increasing at Moore's Law rates, computation demand is increasing faster. The global power demand for computing and data distribution may someday exceed a terawatt. Power consumption limits the continued exponential expansion of new information technologies, restricting the growth of the semiconductor industry

II. Power From Space

The earth intercepts 174 thousand terawatts from the sun. 120 thousand terawatts passes through clouds to reach the surface, warming the earth to a black-body temperature T_{bb} of 255 K, -18 °C. Most of that power lands on ocean, and the power reaching land is mostly gathered by plants drawing CO_2 out of the atmosphere. Land covered with solar photovoltaics can displace carbon emission by power plants, but it also displaces natural carbon removal by soil microbes, trees, deep-rooted grasses, and other perennial plants. Destruction of natural ecosystems by agriculture [10] [11] has already brought

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significant climatic change. The pumped storage reservoirs needed to timeshift solar power, and the inefficiencies of storage and power transmission that increase their extent, will disrupt nature further.

The sun emits 380 trillion terawatts into empty space. 600 million terawatts of 24x7 sunlight streams through the region of space closer than the Moon's orbit. Diverting 100 terawatts of that power to the Earth's surface could power the entire world at US levels of energy consumption, while increasing the Earth's surface temperature by only 0.05 °C . 100 TW can also convert up to 60 ppm of atmospheric CO_2 into elemental carbon and oxygen per year. Space energy can provide massive benefits to earth.

In 1968, Peter Glaser proposed capturing terawatts of space power in geosynchronous orbit, converting the power to 2.45 GHz microwaves with vast space solar power satellites (SSPS), and beaming it to equally vast rectifying antennas ("rectennas") on the earth, which would convert it to grid power [12]. Transmitting and receiving antennas are scaled by diffraction limit over 39 000 kilometer distances - 12 centimeter waves result in antennas 5 kilometers across, assuming 25° above-horizon elevation and 9% sidelobe loss.

2.45 GHz SSPS may interfere with terrestrial communications and radar. Sidelobe power from a single 5 GW SSPS satellite is predicted to be 1mW/m^2 300 km from the rectenna [13], more than 70 dB higher than the Earth's thermal background.

Alternatively, space power may be beamed as 183 GHz millimeter waves [14] to 20 km altitude aerostat [15] rectenna platforms in the stratosphere, above the winds and shielded from the surface by tropospheric water vapor. Transmit and receive antennas could be 75 times smaller than 2.45 GHz SSPS proposals, and run at higher power densities than sunlight. Even scaled down, this is a huge first step, and we do not currently have the technology to efficiently transmit and receive 183 GHz power.

Instead of beaming low value energy at enormous power levels to vastly expensive rectennas on earth, with incredibly high initial costs, what if we turn space power into high value, scalable, easy-to-transmit products - like information?

III. Global Data Transmission

Radio broadcasting works because vast amounts of information can be encoded in tiny amounts of energy. Shannon teaches that information can be represented with an energy of $ln(2)kT$ per bit, 2.9e-21 joules at 300K, or 26e-24 joules (26 yoctojoules) at the 2.7K cosmic blackbody temperature. Information transmission requires enough power to overcome ambient thermal and artificial noise. For example, across the 2.45±0.05 GHz ISM band, the earth emits 20 pW/m^2 and receives 20 fW/m^2 from the sun. This means that a small antenna on an IEEE 802.11g USB stick can receive 54 Mbps data from a 20 mW transmitter tens of meters away. Point-to-point information transmission can use much less power and tolerate far higher losses than bulk power transmission.

Cisco estimates that global IP traffic will exceed 1.1 zettabytes per year in 2016 [16], averaging 280 terabits per second.

Even with 1% power-to-microwave conversion efficiency, and 90 dB path loss, all global internet traffic can be received with 20 dB signal-to-noise ratio with only 200 MW of transmitter feed power, and 1 MW total broadcast power divided among millions of individual receivers on earth. This is 40 dB less than a single space solar power satellite delivering 5 GW to the grid, and it will occur at frequencies much higher than existing services, creating no interference.

Existing geosynchronous (GEO) satellite internet services are "bent pipe" up-and-back paths relaying traffic to and from the wired internet. A request-and-response transaction makes four 38 000 km journeys through space, adding 510 ms of delay to an internet transaction, as well as significant queueing time for the bitrate-limited link. Latency (round trip ping time) is at least 550 ms, typically 700 ms, and can exceed 1500 ms when the link is saturated [17].

Can we do better? What if servers orbit closer than GEO?

IV. Space Power's Solid State Makeover

Satellites are essentially energy-processing surfaces, converting sunlight into information broadcast to earth. Ivan Bekey teaches us to replace structures with information, build gossamer structures in distributed systems, and transport energy and information, not mass [18]. Middle Earth Orbit (MEO, >2000 km altitude) is subject to extremes of radiation and temperature, but is free of friction, contamination, and mechanical stress. Satellites have line-of-sight access to vast areas of the earth. Low drag orbits are precisely predictable.

Mesh networks can connect thousands of small satellites in a three-dimensional obstruction-free environment [19]. Thin satellite array function-to-weight ratios can be orders of magnitude better than terrestrial infrastructure or aircraft-style satellites.

220 nm thick direct-bandgap indium phosphide photovoltaic cells collect sunlight with 15% efficiency, 200 W/m^2 [20], weighing 1 g/m^2. More efficient multilayer cells are possible, but are far more expensive and vulnerable to radiation.

Integrated circuit silicon is lightweight. The lifetime power cost of a typical microprocessor is higher than the production cost. Thinned to 20 μm, a 10 mm^2 die weighs 500 μg. It is far cheaper to move silicon to a power source in space than to move space power to terrestrial silicon.

Integrated circuit chips for RFID tags are as small as 50 μm x 50 μm x 5 μm, draw milliwatts of power, weigh 30 ng, cost a fraction of a cent, yet contain thousands of 90 nm transistors [21] [22]. Cost and size will plummet exponentially with time.

V. Server Sky

Server sky [23] [24] proposes migrating gigawatts of data center computation into a ring of satellite arrays orbiting the earth, directly servicing users between 40° north to south latitudes. Individuals can communicate directly to arrays in the

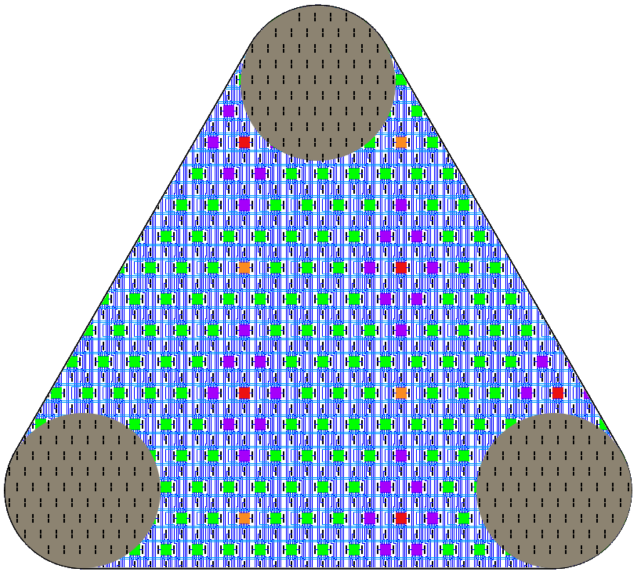

Fig. 1. Thinsat back side chip array, 20 cm wide, 70 μm thick, 5 g, not to scale, real thinsats will have 1400 2.1 mm slots and 350 chips. The black vertical bars represent slot antennas, the corners are electrochromic light pressure thrusters. Antenna slots pass through the aluminum foil substrate to the front, covered with InP photovoltaic cells and corner thrusters

sky, through their own satellite antennas, or antennas on cell towers, without landline infrastructure. Arrays will originate or proxy content and services without an additional round trip to earth.

Server sky communication is point to point, using 70 GHz, 4.3 mm, phase-array-steered beams to paint sub-kilometer ground spots. Cross-orbit and intra-array communications in vacuum can happen at 60 GHz. That frequency is strongly absorbed by atmospheric oxygen resonance and does not reach the ground.

The primary task of server sky arrays will be data center computation; retrieving and formatting data from solid state memory, data analysis, simulation and modeling, video and sound, synthesis and recognition.

Server sky **thinsats** will be rounded triangles 20 cm across, 240 cm^2 in area, and weigh 5 g. Thinsat front sides will be covered with indium phosphide solar cells that directly power silicon chips millimeters away.

Thinsat back sides, illustrated in Fig. 1, will be covered with 1400 2.1 mm slot antennas in a hexagonal grid at full-wave spacing, cut through a 70 μm thick aluminum substrate [26]. Groups of 4 slots are fed by one of 350 3.6 mm x 3.6 mm x 20 μm thick customized integrated circuits, all with built-in RF power modulators fed by the nearest of 12 intermediate frequency synthesizers. The rest of the chips are a mix of simple microprocessors, ROM, and RAM, and connected by a redundant mesh of low voltage high speed wiring. Security will not be a software afterthought - encryption and decryption will be performed by dedicated hardware invisible to software. Advanced semiconductor chip design is complex and expensive; the high non-recurring engineering expenses will be spread over billions of production die.

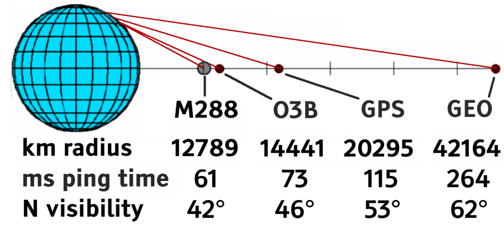

Fig. 2. Server sky M288 equatorial orbit radius, round-trip ping time, and northern visibility with 20 degrees elevation, compared to other orbits. Relay satellites such as O3B and traditional comsats do not originate data, so round trip pings will make two passes through these satellites, doubling ping time.

The larger-than-halfwave spacing will create grating lobes spaced 60 degrees from the main downlink lobe; Fortunately, the earth occupies less than 60 degrees of the sky visible from the server sky orbit, so waste downlink power will disperse harmlessly into empty space. The sidelobe waste power is defocused by thinsat curvature, frequency spread, and the nonuniform array. There will not be enough concentrated power to interfere with other services, though sidelobe waste from hundreds of millions of arrays may someday raise the noise floor.

Thinsats will deploy into actively stabilized three dimensional geodesic arrays. Array sizes can vary from hundreds to millions. This paper considers arrays of 7842 thinsats, producing an average of 24 kW for computation and radio.

Server sky orbits will not be geostationary. Thinsats will be launched in 40 kg solid-cylinder stacks into 6411 km altitude equatorial orbits, about twice the radius of the earth. This is in the inner van Allen belt, a high radiation zone with few other active satellites. Compared to GEO, the MEO orbit reduces round trip ping time, path-length attenuation, and the size of the ground footprint for point-to-point communications.

Arrays will pass through the sky five times a day, every 288 minutes, so this orbit is called **M288**, as shown in Fig. 2. In the northern hemisphere, the M288 orbit appears close to the southern horizon, below 20° elevation from latitudes above 42° N.

Most of the developing world's population is below 42 degrees north as shown in fig. 3 [27]. Farther north, and near midnight, server sky arrays can relay through existing constellations such as O3B, Iridium, and ViaSat to polar and insomniac customers.

Arrays will eclipse 17% of every orbit in spring and fall, 11% in summer and winter. Arrays will go into cold shutdown when eclipsed, while other visible arrays in full sunlight continue serving customers. Extra arrays are cheaper than batteries.

Server sky data centers do not need chip packaging, power conversion, air conditioning, land, structure, or fiber data links. Thin film space systems assembled with photolithography and automation may cost less less than traditional earthbound systems, with more versatility and fewer environmental costs.

A booster such as India's PSLV [28] can put 24 40kg arrays

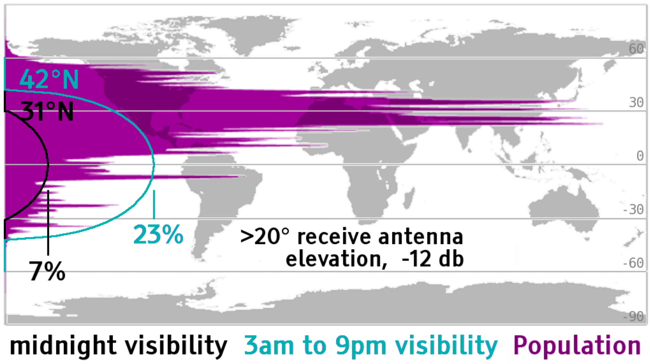

Fig. 3. Population and array visibility for 20° minimum antenna elevation. The vertical axis is latitude south to north, and the horizontal axis represents M288 array midnight and daytime visibility vs latitude, and world population vs latitude. Array visibility is lower at midnight because arrays are eclipsed by the earth.

(with spares) into equatorial M288 orbits (5 overhead passes per day, 288 minutes apart). Any launch system capable of 10 km/s delta V can dispense dozens to hundreds of server sky arrays.

VI. Space Power Transformed

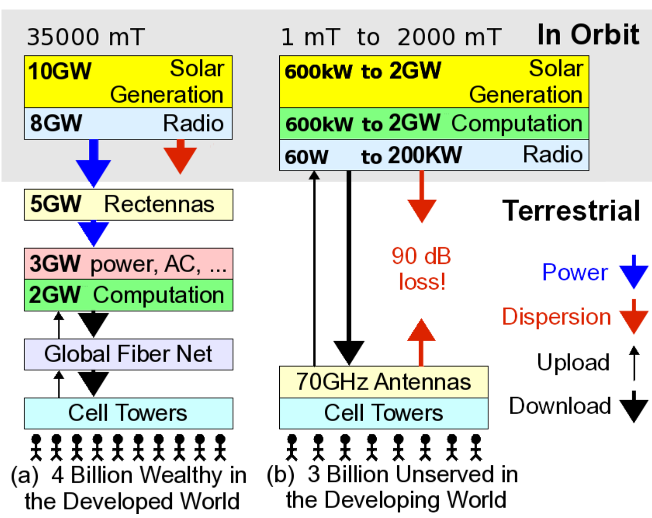

Fig. 4. (a) One minimum size 10 GW Space solar power satellite feeding terrestrial data centers. (b) Constellations of server sky arrays broadcasting directly to customer cell towers. Server sky can start profitably with an 600 kW constellation of 25 arrays, and grow exponentially.

Fig. 4 shows two different ways space power can be used to power the internet. The first column represents a 10 GW SSPS satellite and one terrestrial rectenna feeding the electrical grid and powering data centers. The second column represents the power used directly in space to feed as few as 25 arrays of thinsats, scaling up to 80 000 arrays, 630 million thinsats, matching current global data center productivity. Optimization reduces launched mass at these high production levels.

Due to diffraction limits, everything about space power transmission must be large; 35 000 tonnes of material launched into orbit for a single SSPS satellite. The complex path power takes from photovoltaic cells in space to a user such as a terrestrial data center has many energy conversion steps. Radiating end-user waste heat into a 300K ambient environment requires more power to extract and dissipate it. PV-to-compute-load efficiencies may be lower than the 20% shown.

The second column represents Server Sky, moving electrical power directly from PV to the compute load centimeters away. 32 kW of full illumination computes and narrowcasts data over a microwave link that can tolerate high (90 dB!) inefficiencies. 20 sunlit arrays out of 25 can provide complete 24 hour coverage near the equator. There is room in the M288 orbit for millions of arrays. As the constellation grows exponentially, many more launch rockets will be mass produced, and the aerospace “experience curve” will reduce launch costs significantly.

Server sky does not eliminate the need to make terawatts for other purposes - it merely increases the efficiency of a few of those terawatts, producing scalable revenue from a much smaller beginning. The greatest obstacle to space solar power is inadequate and expensive launch capacity. Server sky, growing at Moore’s law and internet rates, can pay for and rapidly develop that launch capacity.

Server sky can be the kindling for a flame that has proven too difficult and expensive to ignite for half a century.

VII. Light Pressure Maneuvering

Thinsats will have area-to-mass (“sail”) ratios of 5 m^2/kg, maneuvering as light sails such as the Japanese Space Agency’s IKAROS [29]. Heavier than true solar sails, thinsats will have enough thrust to travel in formation, avoid colliders, and migrate from underutilized arrays to larger ones.

1360 W/m^2 sunlight makes a tiny 4.54 μPa pressure if absorbed, and double that if reflected. The three corners of a triangular thinsat will be 5 cm diameter (19.6 cm^2) electrochromic mirrors, which electrically switch from dark to reflective, changing acceleration by 3.5 μm/s^2, or turning in 15 minutes.

Accelerations will be small, but accumulate to large displacements over hours and months. A thinsat can move in nanometer increments, or move 40 000 km, halfway around the M288 orbit, in half a year.

VIII. Radiation

Radiation will be the number one problem for server sky thinsats. Recent advances in solar cell materials and VLSI radiation hardness, a fortuitous result of transistor scaling, permit unshielded gram-scale satellites.

The Intel hafnium oxide gate stack, designed to reduce gate leakage, produces transistor gates highly resistant to charging by ionizing radiation [30]. Modern digital processes operate at supply voltages too low to sustain latch-up. New microprocessor designs that recover from noise errors [31] can evolve into designs that recover from radiation-induced single event upsets. Thin indium phosphide solar cells can survive radiation doses of 10^{18} electrons/cm^2 (1 MeV) [20].

IX. Geodesic Arrays, Radio, and Ground Patterns

The 1.1 million antenna slots on 7842 thinsat subarrays combine into a giant 100 meter aperture antenna. The array of thinsats is shaped like a distorted geodesic sphere, which can beam packets to sub-kilometer-sized receiver footprints on the ground. Server sky internet cannot compete with optical fiber in a dense urban environment, but works well for suburban, rural, and mobile customers, in emergencies, and in war zones.

An intriguing ground antenna design from Kymeta [32] [33] uses liquid crystals in a metamaterial configuration as a Ka band antenna. These antennas steer slowly (30°/s) and are not suitable for time-sharing many users to many server sky arrays at once. Presumably, these antennas can evolve to faster LCD materials and shorter wavelengths, so they can timeshare between multiple arrays in orbit.

Uplink from small antennas will be slower than downlink. This matches typical asymmetrical internet usage. There will be few customers in the mid-Pacific, so bulk content can be uploaded from large high-bandwidth surface antennas sited near trans-oceanic data cables.

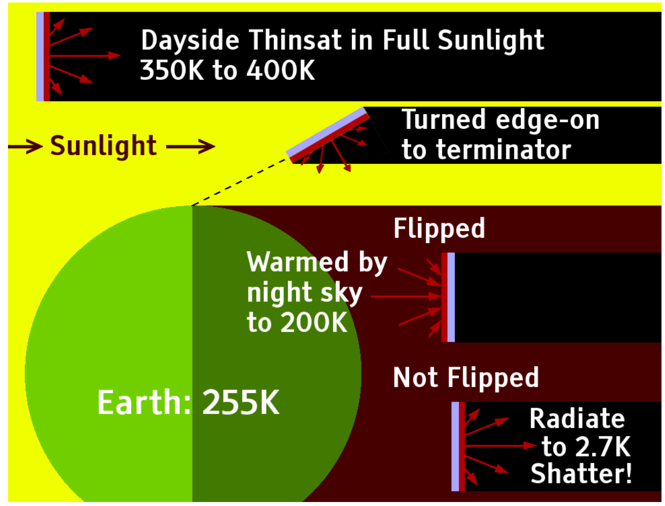

Fig. 5. Filtering infrared to emit away from the sun permits thinsat mass reductions. Turning thinsats edge-on to the terminator (the day-night boundary) prevents sunside reflections from making light pollution in the night sky. Turning the infrared emissive backside towards the earth keeps the thinsat warmer during eclipse, reducing thermal stress and increasing reliability.

X. Light Pressure, Ballast, and Space Resources

Light pressure distorts orbits, shifting apogee and perigee eastward (viewed sunwards). The minimum eccentricity of a precessing orbit increases with sail ratio (area over mass) and orbit radius. The elliptical orbit must not precess into the paths of other satellites, limiting the maximum sail ratio and the minimum mass.

The minimum mass can be reduced by half if light pressure from the sun on the front is balanced by infrared emissions out the back. A frontside conductive grid with a mesh size of 2 micrometers can pass and focus optical photons on the photovoltaics, while reflecting (and not emitting) longer infrared wavelengths. A high emissivity black coating on the thinsat backside will radiate the heat isotropically, and half of the infrared light pressure will be directed forwards, opposing the light pressure of incoming sunlight.

Launch mass can be reduced further by attaching ballast mass in orbit. Recycled obsolete thinsats will be one source of ballast, gram-weight pellets cut from captured space debris will be another. This makes space debris into a valuable resource; hopefully we will capture and re-use all of it before plummeting rocket costs reduce the relative profitability of space debris recycling.

XI. Environmental Effects

If space computation power grew to a terawatt, 250 billion thinsats facing the sun at M288 could reflect 25% as much light into the night sky as the full moon, disrupting nature and optical astronomy. So, thinsats will turn edge-on to the terminator in the night-side half of the orbit (see Fig. 5) to eliminate night sky light pollution, reducing average power by 17%.

Thinsats cool rapidly in eclipse, Turning the high thermal emissivity backside coating towards the nearby warm earth (see Fig. 5) minimizes thermal shock. This protective measure encourages light pollution minimization turns.

High latency computation tasks should deploy further out. At lunar-distance Lagrange points, arrays are in continuous sunlight and have better access to lunar materials, while worst-case light pollution is reduced by a factor of 3000. It is difficult to imagine how humanity will use more than 1 MW of computation per capita, but as recently as 1896, Arrhenius could not imagine reaching CO_2 levels of 400 ppm in less than a millennium.

When forecasting the consequences of our engineering designs, we should think about millenia and exponentials, not mere decades and S curves. Learn from nature, and choose designs that make environmental protection and material re-cycling the most profitable way to operate, without relying on good intentions.

XII. Ownership and Security

Server sky thinsats will be owned and used by people with few security skills, and will sometimes run insecure, poorly-designed software. The thinsats connect to an entire planet of spies, criminals, and cyber vandals. Defending thinsats will be difficult but not impossible.

Thinsats will contain large arrays of inexpensive one-time pad using ICID technologies [34]. Bits may be extracted at at the wafer level during manufacturing, but are otherwise impossible to predict or intercept.

Thinsats will use custom chips designed for survival and reliable computation in a high radiation environment. The same hardware that corrects radiation single-event upsets can be applied to security tasks. Thinsats will have built-in cryptographic hardware primitives to perform kilobit integer arithmetic and other useful primitives found in most secure encryption algorithms. Large integer results can be tested with a verification modulus [35] (a "woop" [36]) computed with a small, randomly generated prime number.

Thinsats have many processors, and the user portions of each processor can be temporarily rented by others. These "proplets" [37] will communicate to a restricted set of ground users, identified by affiliation, geography, and time. Thinsats work at the speed of light. Physical attacks require slow satellite rendezvous, allowing hours for countermeasures or self-destruction.

Thinsats can be transferred as property, or used as collateral for loans. Hardware implementation of "smart contracts" [38] permits automatic transfers to lien-holders if payments are not made or terms are violated. This lowers transaction costs and interest rates, permitting new borrowers without trustworthy credit histories to establish them.

These capabilities are fragile if the owners and users are inept, gullible, and isolated. Server sky will support protocols for users to team with friends, family, and trusted professionals to authenticate important transactions.

All security protocols fail over time; they may be compromised, or merely obsolete and inefficient compared to newer protocols. Accumulating radiation damage, and new generations of higher performance thinsats competing for the same orbits, will eventually force the retirement and recycling of obsolete thinsats.

XIII. Serving Clients

The developed world needs help extracting itself from the material consumption trap. Unleashing the creative power of billions of people can bring new ideas, new inventions, and economic growth rates undreamed of in national capitals and corporate boardrooms.

C. K. Prahalad teaches us that typical "S" curve economic growth is compacted in time into an "I" curve (double-digit percentage growth rates per month) for products that satisfy important needs in the developing world [39]. Our goal is not merely to provide new clients for developed world corporations, but to connect the world to technical, entrepreneurial, educational and cultural products and services invented by billions of newly empowered people.

We offer an alternative to the developing world: replace material resources with information, just as a smart phone embeds vast intellectual resources and value in a few pennies of raw materials. Information manufactured with space solar power can be expanded to vast scale, without extracting resources or dissipating heat in the biosphere. This eliminates the tradeoff between economics and the environment that characterizes the resource consuming technologies of the developed world.

A cruise ship arriving in port emits a flood of passengers flocking to the shops and sights on shore, followed by a flood of crewmembers seeking internet cafes to communicate with their families back home [40]. High bandwidth server sky internet to cruise ships underway will not only provide sporting events and other realtime video to the passengers, but family connection for the crew during the voyage. That increases the value of the cruise to everyone on board.

In 2015, almost 3% of the world's population lives and works outside of their birth country, making the painful choice to leave loved ones and familiar landscapes behind. Many of the passengers cruising on spaceship earth would find their lonely journey eased with video connections, news, and information gifts exchanged with those at home.

Moving remittances (job wages sent home) between countries is difficult and costly with traditional services like Western Union and Moneygram, with fees taking as much as a 10% bite of the transfer [41]. Some guest workers use Bitcoin to transfer money to ebanking services such as Kenya's M-Pesa, avoiding fees and risks. The developing world, with its high percentage of "un-banked" individuals, and high levels of corruption, may develop cashless economies long before complacent and wealthy countries do.

All of this will cause massive cultural change. We must not lose the values and wisdom of the past in our headlong rush to the future. In particular, young and educated people are ignoring their poor and illiterate elders, especially damaging to traditional elder-dominated societies [42]. An elder can verbally dictate her memories and values over voice uplink to server-sky storage, producing thousands of hours of transcriptions, available forever to her descendants, ethnologists, and historians. When her callow children grow old and wise, they will treasure this storehouse of cultural knowledge, as will their distant descendants. One poor village elder can leave a more permanent legacy than the kings of the ancient past.

Some elders claim "I am too old to learn to read". Many Guatemalans are enthusiastic fútbol (soccer) fans, like many in India love cricket. Adults watching sports on smart phones or tablets can choose "education enhanced-sports", providing game information enhancements involving letters, then simple text, growing towards more complex text. An adult version of Sesame Street, with an important difference: each personal channel can individually adapt to the progress of the learning reader, and connect their lessons to those of their friends and neighbors, strengthening friendships and community while building literacy. Machines are patient - if a new reader needs ten years to learn, they will be guided at a comfortable rate.

Education designers can observe individual progress, and evolve better teaching software. The 21st century will progress beyond universal literacy to continuous learning. As new inventions emerge ever faster from a world full of new inventors, new teaching methods developed for adult literacy will help train everyone to master those new inventions and take control of their technological environment.

XIV. Creating Entreprenuers

Creative, newly educated server sky clients will become active providers of local and global content and services. A farmer could tend her crops during the day, and sell her harvest on the Chicago Mercantile Exchange at night. Her brother could drive a robot tractor for a farmer in Iowa. Her sister could teach Kenyan schoolchildren. And next year, they can run businesses employing hundreds of people around the world to do the same. Work globally, live locally.

It is an accident of history that computers are programmed with text; Inca quipu, Mayan and old world weaving, and Jacquard machine-woven brocades were designed and coded visually and tactually. Programs may be created, compiled, and evaluated with other sensibilities; weaving a *huipul* garment or hoeing a weed in a *milpa* cornfield requires preception and skill, which may be transferrable to the creation of software and the visual presentation of information. With the right interfaces, the corn farmers of the past may become the information farmers of the future.

New income can be invested in thinsat hardware. A thinsat might cost $100 to build and launch, affordable by families or village cooperatives. Thinsats can be collateral for loans. When a strong, protected international market develops, this may be the first opportunity many people have to become investors and property owners.

Peruvian economist Hernando De Soto [43] offers evidence that property rights in land and houses foster economic development, providing collateral for loans that purchase materials and tools to start new businesses. Individual server sky thinsats are depreciating capital goods, but are highly fungible and reusable during their functional lifetime. When thinsat cost drops below $100, even the poorest families can afford a "piece of the action". With proper community safeguards, and development environments usable by the uneducated but persistent, those families can develop their "information farms" into valuable properties in the server sky information economy.

Thinsat arrays can be international cooperatives. Since different regions desire different content, "regional" thinsats will source content to the rest of the array, which will synchronize the packets and send them to an owner's customers below as the array passes overhead. If the rules and operation of a coop are not to an owner's liking, she can migrate her thinsat to a nearby array - or simply swap content and ownership with another owner in that other array.

XV. Three Billion New Researchers

Today, ecotourists travel the world searching for nature, while professional scientists travel to gather data. Instead of travelers burning megatons of jet fuel and trampling wildlife underfoot, local people can place thousands of cameras and sensors in the wild places near their villages, observing nature without disturbing it. Villagers selling data from an acre of forest can produce more annual revenue than one-time lumbering, or turning jungle into desert to get at the minerals underneath.

But people can do more than maintain sensors. We will need more minds than ever to interpret this flood of data, choosing what to gather next, finding and understanding patterns, and explaining those patterns to others. Beyond literacy, we should develop a universal ethos of observational science, so that everyone learns what to look for, and why.

In the near term, we can use Server Sky to enhance the scientific and educational potential of existing tropical universities. Remote education programs can be delivered nationwide and worldwide, with computer-assisted speech translation to regional and global languages. We can connect resource-and-equipment-poor researchers in these universities to world-class labs elsewhere, stretching limited budgets and fostering international collaboration.

Remote submersibles in the tropical ocean and satellites in space can be controlled via server sky arrays overhead. One very exciting possibility is controlling small experiments directly on the International Space Station (ISS), collecting vast amounts of experimental data for analysis in Server Sky arrays. ISS is continuously visible from a large swath of the Server Sky constellation, far more visibility due to its altitude and the lack of atmospheric attenuation. Someday, thousands of server sky arrays can provide petabit-per-second bandwidth to ISS and its successors, using frequencies near 60 GHz, and precisely focused beams that do not penetrate the atmosphere. This bandwidth, the automation it supports, and the torrent of data it can return, can enable many researchers to run millions of small experiments simultaneously, 24 hours a day.

Developing world research institutions will have the resources to join their wealthy peers, releasing a flood of new space science accomplishments and discoveries. Every country will become a space power, and the International Space Station will become truly international, the world's largest and most inclusive research center.

XVI. Serving the Future

Human prosperity will no longer be a zero sum game, played at the expense of nature. Indeed, as good stewards and creative inventors, with doomsday pushed beyond the foreseeable future, we can help nature grow richer and more diverse than it has ever been during the long history of life. Information is power, and exawatts of off-Earth power can become information products that serve all of nature. Humankind can become wealthy and smart enough to become nature's collaborators, not merely her cruel and ignorant destroyers.

Server sky arrays will, like foraging ants serving their queen, serve and protect the human societies on Earth that gave birth to them. Myrmecologist (ant expert) Edward O. Wilson writes: *"Laid before us are new options scarcely dreamed of in earlier ages. They empower us to address the greatest goal of all time, the unity of the human race."* [44].

Server sky can be a first step towards opening the rest of the solar system, and beyond. Intelligence, mind and machine, can build gardens of life in space, and someday connect earth life to the stars.

Wilson again: *"Someday, perhaps in this century, we, or much more likely our robots, will visit these places in search of life. We must go and we will go, I believe, because the collective human mind shrivels without frontiers. The longing for odysseys and far away adventure is in our genes."*

The authors of this paper are still discovering new opportunities for server sky, and for information resources provided from space, by developing world creators, for the world. We hope GHTC2015 will connect us with innovators from around the world, who will suggest more improvements and opportunities.

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