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Position Paper for the IAB workshop on Environmental Impact of Internet Applications and Systems, 2022

Abstract – A main objective of this submission is to contribute to and strengthen the contextual canvas and background baselining for the discussions and presentations at the actual IAB e-impact workshop.

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On Principles for a Sustainability Stack

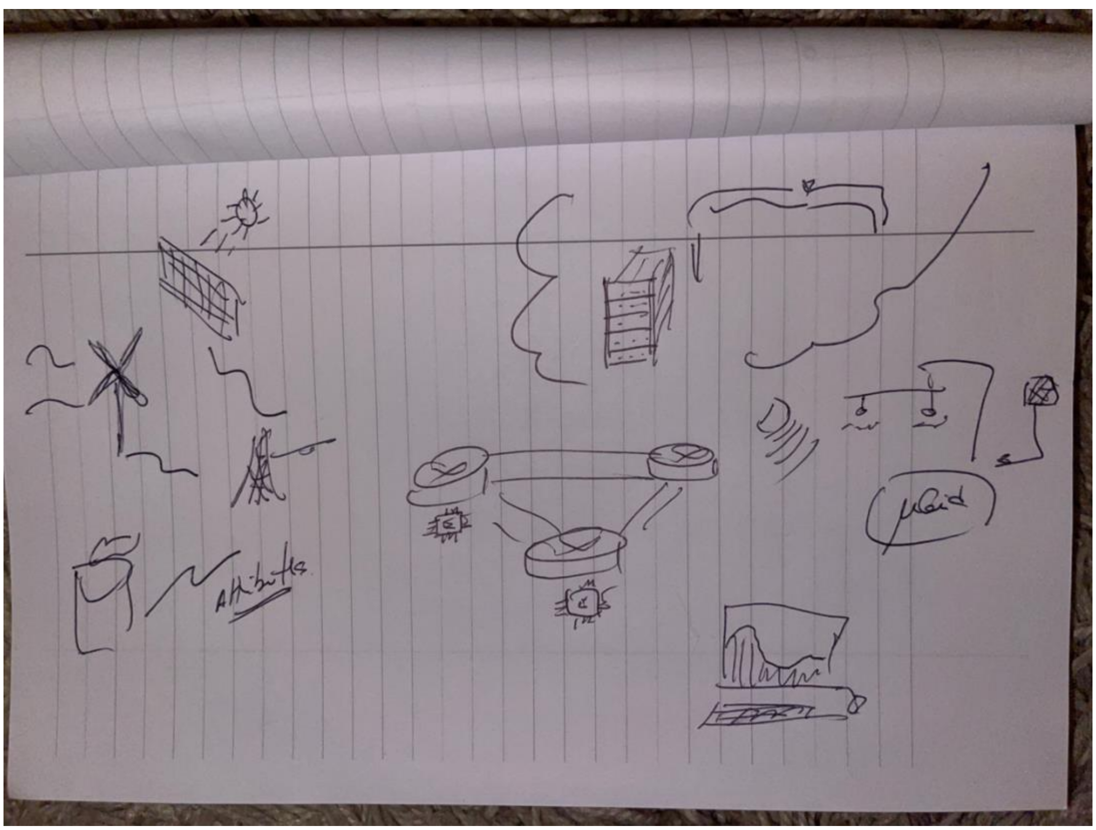
Background

Historically, digital communication networks and internetworks are optimized following business metrics, and as such broadly prioritize e.g., performance, cost, and availability. Most recently, there have been notable advances in network elements and sub-elements optimizing metrics related to technology sustainability and environmental impact, such as energy efficiency improvements. Many of those optimizations are typically local in nature, sprinkled within an architectural canvas. An opportunity for maximizing the positive environmental impact of these technologies calls for a systemic view, an architectural constellation of interconnectedness within what we call a “sustainability stack.”

Impact to the environment happens in a plurality of categories. To name a few, Global Warming Potential (GWP), ozone depletion, acidification of soil and water, eutrophication, depletion of abiotic resources, human toxicity, and freshwater aquatic, marine aquatic, and terrestrial ecotoxicity. This position largely focuses on GWP or a product's carbon footprint, not diminishing the importance of all the others.

Local Optimizations

As an ecological system assimilates and incorporates change and stimuli to retain its main function, a communications inter-network's dynamics undergo continuous change as well. This capacity provides temporal resiliency to the evolving system. An increasingly large disturbance on the requirements imposed to communication systems comes from various vectors of environmental impact: from greenhouse gas emissions associated with the entire product lifecycle, product energy usage effectiveness and economic cost, regulatory and compliance forces, NetZero alignment, and mindshare on preserving our only Planet.



This visual shows several sustainability local optimizations, such as:

- Renewable and low-carbon power sources and usage
- Energy efficiency improvements in chips, optics, and power supplies
- Lower power usage effectiveness in data centers from new cooling techniques
- Reduced power loss, from input power to network element components in a DC

These local optimizations have little systemic interaction, and their compounded impact is underutilized.

Principles and Understudied Characteristics for A Sustainability Stack

This document identifies four key characteristics of sustainable internetworks:

1. Emergence: While there are local sustainability features in network elements, sub-elements, and endpoints, their end-to-end orchestration produces new properties and compounded benefits from their interaction, not reflected in the components.
    a. Corollary: attributes specific to sustainability need distribution mechanisms
2. Multi-objective optimization: Introducing sustainability goals generates tension with {performance; reliability, and availability} objectives. If, e.g., the total combined benefit to profit, planet, and people is a function of the two independent variables of availability and sustainability, then global maximums are found tunning this tradeoff.
    a. Corollary: A simple optimization of only one of the objectives (e.g., maximize availability only) will not yield total benefit optimizations. Aimlessly (open-loop) adding redundancy would reduce utilization and effectiveness.
3. Compounded impact, and observer effect: since there are sustainability impacts inherent to generating and using energy and operating interacting network elements, adding new features to improve environmental impact postures would create an

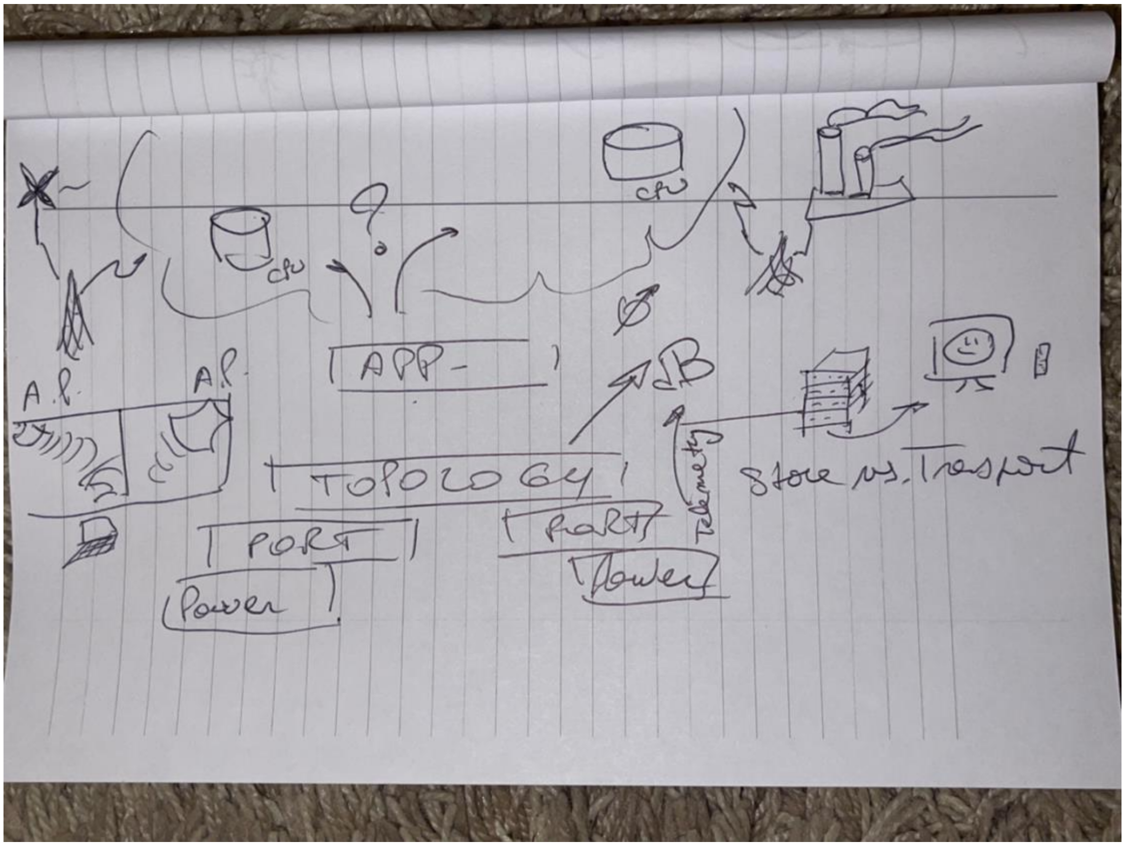
additive component of e-impact as well. This component ought to be accounted for, in addition the environmental benefit component(s) it creates.

4. Data Layer: Parallel to the inter-network architecture, there is a data architecture formed by several uncorrelated data sources and their associated meta-data, access controls, and attributes. These include time-series (e.g., power usage as a function of time) and space-series (e.g., power usage as a function of a graph), attribute metadata such as geo-location, emissions factor, sleep state.
    a. Corollary: a meaningful powering and depowering of various paths within the data layer is a function of the reaction speed between the recognition of the need to add or reduce capacity, and the ability to adjust that capacity. Meaningful timeframes here can be anywhere from tens-of-minutes (e.g., from the start of a cold-boot of a core device until network stability and convergence is achieved), to the few milliseconds supportable with 802.3az.
5. Cross Layer and Cross Protocol Optimizations: an attempt to optimize one layer or one protocol without the global view of the stack may be moot to counterproductive. For instance, the use of broadcast is a key contributor to energy consumption in network protocol. Yet, the claim to use multicast at layer-3 may place a pressure at layer-2 that represent a higher cost than if layer-3 was using plain broadcast but better control the scope where broadcast is needed. In other words, the optimization has to observe all aspects of the stack and their mutual interaction to effectively ensure that benefits can be derived overall.

Interestingly, these principles and characteristics have equivalents in ecosystems and other interactive organizations (which is left for subsequent writing.)

A Sustainability Stack Example

An exemplary sustainability stack is hereby shown:



We can identify the following end-to-end properties and actions in this stack:

- Ports that are unplugged are logically turned off, PHYs shut down, and moved to low-power modes, and
    - Unused ports (e.g., parallel links with aggregate bandwidth usage less than a member link in a group) are shut down.
- An orchestration function, fed with utilization seasonality prediction, can identify redundancy (i.e., paths under-utilized that minimally contribute to resiliency) and place ports, links, and nodes in low-energy mode (e.g., sleep mode), slow-motion

mode (i.e., underclocked CPUs, shaped traffic), meditative mode (e.g., aware, present, topologically participating but not passing traffic), or even fully shut down.

- Workload placement can optimize specific sustainability attributes (e.g., moving workloads to DCs with renewable energy at a given location and time would improve greenhouse gases emissions from energy generation).
- Application benchmarking for CPU and GPU efficiency can dictate application placement.

We can also establish some exemplary data attributes in the system:

- Power usage telemetry is available through APIs (application programming interfaces) on network elements, and
    - Power usage telemetry data is aggregated by a data layer, and further aggregate made available through northbound data platform APIs.
    - Power usage telemetry is tagged with meta-data, including sustainability-related attributes such as geo-location, emissions factor (i.e., renewability index of the energy), and others.
- Link-state distribution, discovery, and protocol information elements are augmented with power utilization and sustainability data.
    - This link-state topology graph and associated sustainability metrics and attributes is exported (e.g., via BGP-LS) to an external database for orchestrator optimization analysis.
    - Analytics that correlate network capacity planning and projected utilization with per-information-unit power efficiency (i.e., power to store a bit and to

move a bit,) and temporo-spatial emission factors (emission factors at various times – solar energy during the day – and various locations.)

- Power usage as a function of time, and in a multi-dimensional representation following the topological graph, is baselined and benchmarked.
    - Seasonality is predicted with various periods (i.e., day versus night usage, high-peak winter vs. low-usage in summer, holidays, etc.)
- A to-be-defined 'green-ness' index can be applied to Data Centers, based on a combination of energy emission factors, location, PUE (Power Usage Effectiveness), cooling techniques, and this index exported as sustainability data.

Additional Environmental Impact Considerations

There are some key areas of consideration of environmental impact of Internet applications and systems, specifically within scope for the design of Internet protocols and architectures:

- Digital Twin and Automation – A network digital twin models certain aspects of a real network in the cyberspace. One main value for that model is to run what-if scenarios and observe the impact on the network, without the need of actuating changes on the real-world network. Applied to sustainability, a digital twin can model energy usage through paths as functions of hardware and flows, or reliability in presence of various low-power scenarios, and assess whether rerouting flows to turn off networking devices is effectively an overall win for a particular level of the network utilization.

- Machine Reasoning, Machine Learning, and AI – Whether is to build models in digital twins or in production networks, experimentation with key learning technologies is encouraged, to predict outcomes, evaluating the environmental impact of using these tools themselves.
- Protocol Design – Many current Internet protocols leverage aspects of increased chattiness, verbosity, and constant periodic keepalive messaging as a key approach to provide, within an architecture that is considered unpredictable, valuable discoverability, resiliency, recoverability, and availability. At the same time, the IETF has also designed protocols that optimize power efficiency under constraints, as well as coating the underlying protocol interaction removing variability and adding predictability. As a position, the latter has broader applicability than the original target.
- Bottoms-up, in addition to Top-down – this paper recommends further study in the complementarity of simple, bottom-up power-saving approaches to also complement the more complex orchestrated controller-down approaches. Today controller-down approaches are limited by the realities of internal network element design. For example, network elements have largely been designed to meaningfully benefit from power changes such as the powering down of a full line-card. If, in the future, instantaneous link rates and ASIC clock speeds can be quickly and hitlessly tuned to match current demand, much more aggressive de-powering within the network element becomes possible. And from there, more granular and reactive tuning at the network level can be attempted.

Conclusion

End-to-end sustainability in an inter-network or digital communication system (i.e., equal or better user outcomes with less environmental impact) involves cross-leveraging:

(1) Discrete, granular, reactive, and local sustainability features in an orchestrated fashion and new sustainability systemic behavior emergence,

(2) Sufficient traffic visibility and future demand predictions to allow for just-in-time capacity increases.

(3) Pareto-efficient choices, as e.g., removing some redundancy can improve sustainability without compromising availability, or underclocking can reduce power consumption without application-level noticeable performance degradation,

(4) a data architecture with proper origin validation and access controls, and analytics to identify global maxima, and

(5) an increasing-value phased architecture: visibility, insight, management, and automation.

Acknowledgements

The subject matter of this work sits at the intersection of technology and planet sustainability; as with other multi-disciplinary topics, key expertise is required in each of both fields, as well as in the intersection.

This work builds upon the diverse experience, expertise, and education (e ^ 3) of its contributors, who are grateful to the genericity of all their coaches, teachers, mentors, and role-models upon which it builds. We truly hope that these bits have net-positive e-impact.

With thankfulness and recognition to Phil Remaker and Yannis Viniotis, for providing thorough reviews and insightful comments.