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TIME AND CONTEXT VARIABLE TOPOLOGIES (TCVT) FOR SUSTAINABILITY-AWARE NETWORK OPERATIONAL FOCUS MODES

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ABSTRACT

Techniques are presented herein that leverage the concept of Time-Variant Routing (TVR) to create time and context variable topologies (TCVTs) that offer a scalable and versatile solution for supporting a proportional response to changes in a network's traffic levels, allowing a network operator to maximize sustainability gains in a network having variable, tidal, and periodic traffic. Aspects of the presented techniques encompass sub-topological planes (which can be made available to a topology as a function of time), network operational focus modes (which employ such planes to create objective-optimized topologies), and mappings between the two. The techniques allow an optimal set of topological elements to be identified based on different variables including, for example, a traffic demand and a renewable energy makeup (e.g., a carbon intensity). By hiding all of the complexity from a user, the techniques offer a simplified user experience through which such a user need only select different network operational focus modes to manage very complex outcomes.

DETAILED DESCRIPTION

When architecting and designing a network for sustainability, a problem that frequently must be solved concerns the creation of proportional topologies. While a network's capacity may be dimensioned to some maximum usage, when the volume of traffic scales down the goal becomes determining how the network may proportionally identify resources to either turn off or place in a low energy state in order to save power. Specifically, over time there are naturally occurring network traffic cycles or "tides" (as in ocean tides), the periodicity and patterns of which a time series can easily be illustrated as a correlation between amounts of data and amounts of energy consumed, as shown in Figure 1, below.

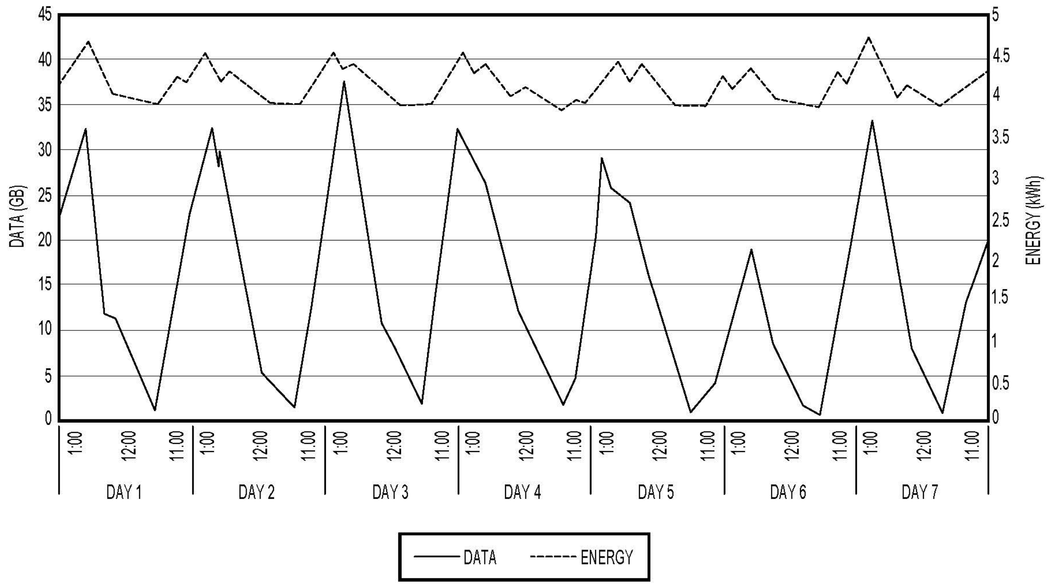

Figure 1: Illustrative Time Series

Consequently, in the presence of tidal traffic a network's routing actions and a topology can vary. This is the high-level concept behind Time-Variant Routing (TVR), as promoted by the Internet Engineering Task Force (IETF) TVR Working Group (WG).

Techniques are presented herein that leverage the high-level concept of TVR, within the context of a proportionality objective as described above, to create time and context variable topologies (TCVTs) that provide a solution that is much more scalable and versatile than currently available solutions. Aspects of the presented techniques support methods for maximizing sustainability in a proportional way for any network infrastructure. By employing the high-level concept of a topology that is time-dependent and time-variant, the presented techniques offer a solution that is more refined and scalable.

Aspects of the presented techniques define two new concepts. First, a sub-topological plane is a construct comprising a subset of the overall topology of a network. Second, a network operational focus mode is a specific network operating posture that may include a number of different variables such as, for example, data traffic trends.

The presented techniques may be understood through a detailed examination of an illustrative example, the initial topology of which is presented in Figure 2, below.

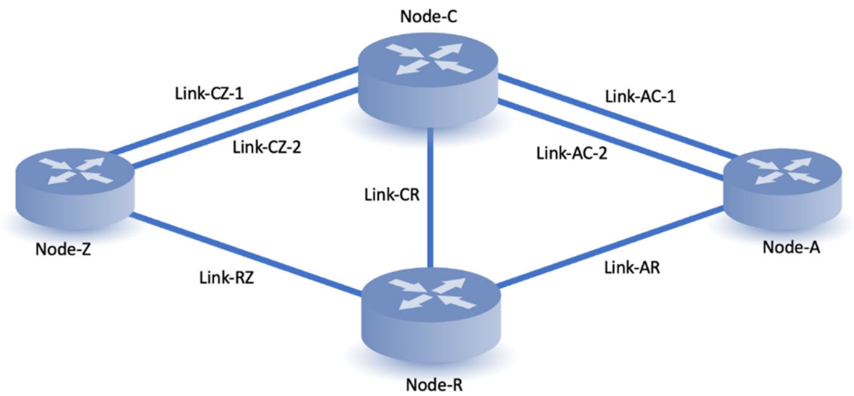

Figure 2: Illustrative Example – Initial Topology

Under the illustrative example, and referencing Figure 2, above, the goal is for traffic to transit from Node-A to Node-Z. During a first step of the presented techniques, various sub-topological planes may be defined based on operational needs. For the instant example, three such planes may be defined, as shown in Figure 3, below.

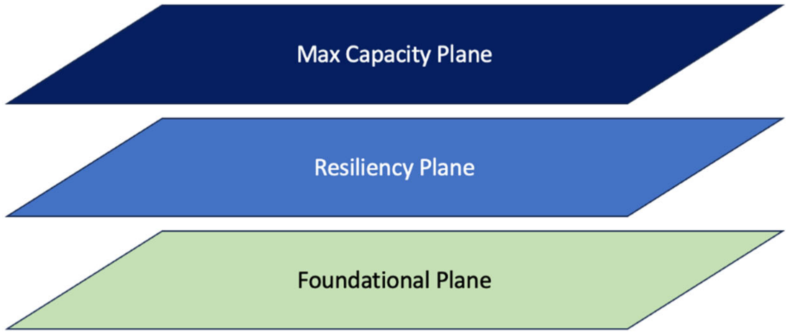

Figure 3: Exemplary Sub-Topological Planes

It is important to note that during this step it is also possible to create other topology-centric postures that are not used for network traffic forwarding but which are employed for operational purposes. For example, there are many northbound activities that frequently take place between a topology's devices and a centralized controller. Those activities may include the sending of a request for an optimized path selection, a sharing of telemetry data for analytics and insights, etc. The time-variant posture (TVP) concept may be extended to accommodate such activities where the type of data that is sent or requested, any optimization requests, and other related northbound activities are all controlled based on the time variant. Under such an approach, the type of data or request that is being shared or sent to the centralized controller may be limited or there may be a change in the cadence at which the data is shared.

During a second step of the presented techniques, each of the topological elements (including, for example, links, nodes, tunnels, etc.) from the initial topology (as presented in Figure 2, above) may be mapped to a single sub-topological plane, as illustrated in Table 1, below.

Table 1: Mappings

Topological Element	Sub-Topological Planes		
	Foundational	**Resiliency**	**Maximum Capacity**
Node-A	X		
Node-R	X		
Node-C		X	
Node-Z	X		
Link-AC-1		X	
Link-AC-2			X
Link-AR	X		
Link-CZ-1		X	
Link-CZ-2			X
Link-RZ	X		
Link-CR			X

At the end of the second step, each topological element has been mapped to a single sub-topological plane. The results of that mapping are depicted graphically in Figures 4A through 4C, all below, each of which visualizes one of the three sub-topological planes.

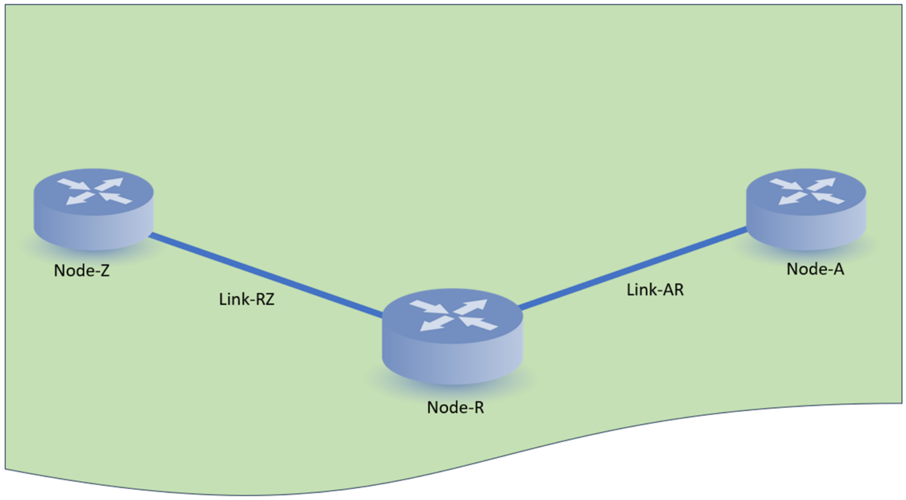

Figure 4A: Foundational Sub-Topological Plane

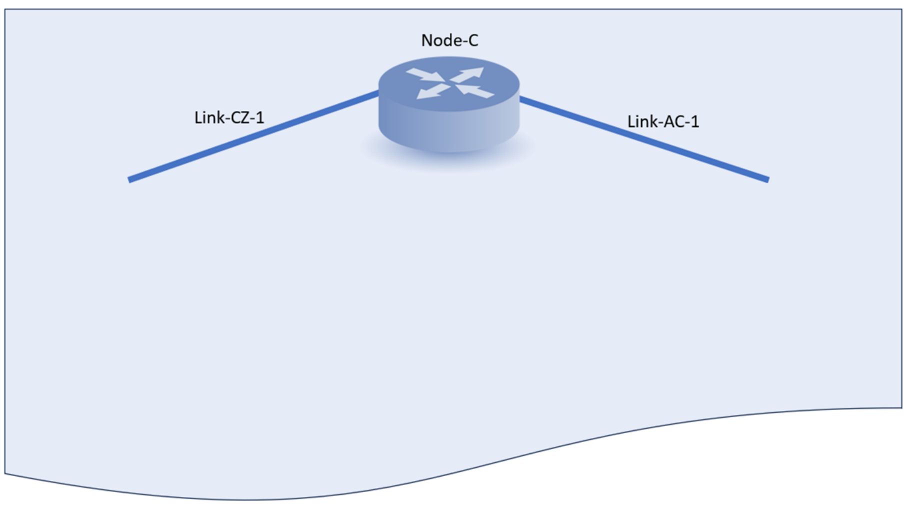

Figure 4B: Resiliency Sub-Topological Plane

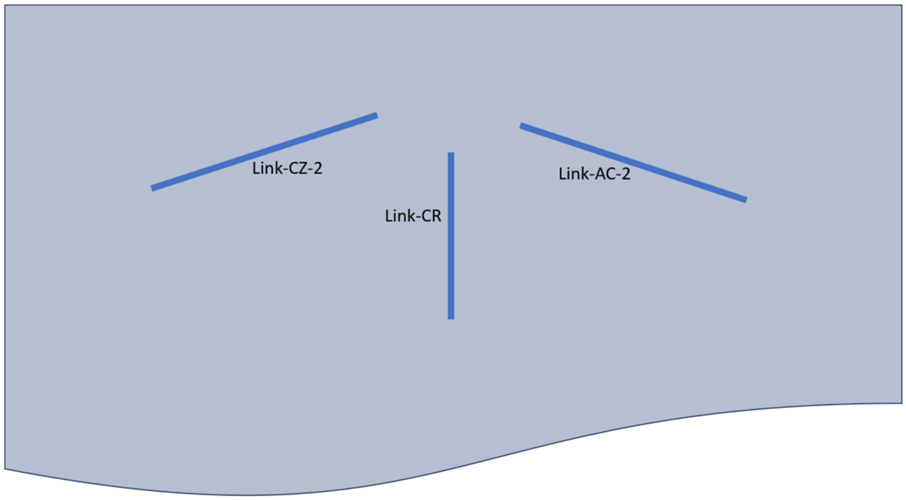

Figure 4C: Maximum Capacity Sub-Topological Plane

During a third step of the presented techniques, the desired network operational focus modes may be created after which the different sub-topological planes may be associated to those modes, as depicted in Table 2, below.

Table 2: Network Operational Focus Modes

Network Operational Focus Mode	Sub-Topological Planes
GREEN Focus Mode	Foundational
TRADE-OFF Focus Mode	Foundational + Resiliency
FULL-ON Focus Mode	Foundational + Resiliency + Maximum Capacity

Using such an arrangement, an operator may select a network operational focus mode based on various criteria such as, for example, the seasonality of traffic. As just one possible example, an operator may establish the exemplary categories that are depicted in Table 3, below.

Table 3: Exemplary Categories

Category	Network Operational Focus Mode
Default	TRADE-OFF Focus Mode
During the night	GREEN Focus Mode
During peak traffic periods	FULL-ON Focus Mode
During holidays	TRADE-OFF Focus Mode
…	…

It is important to note that the different categories of network operational focus modes that are shown in Table 3, above, are exemplary only, and a network operator may create other, and possibly more complicated, time-based, date-based, etc. categories based on their needs.

Continuing with the instant example, and referencing Figures 4A through 4C, all above, the different associations from Table 2, above, may be depicted graphically in Figures 5A through 5C, all below, each of which visualizes one of the three Table 2 associations.

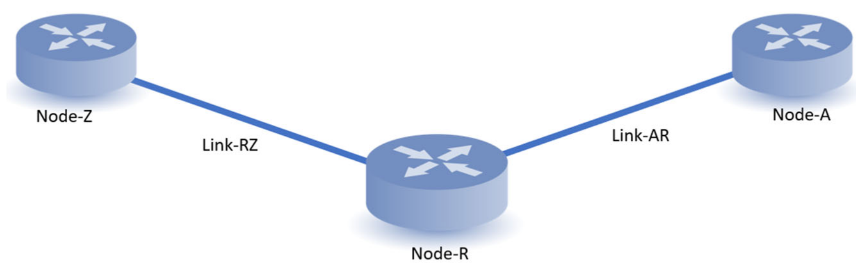

Figure 5A: Green Network Operational Focus Mode

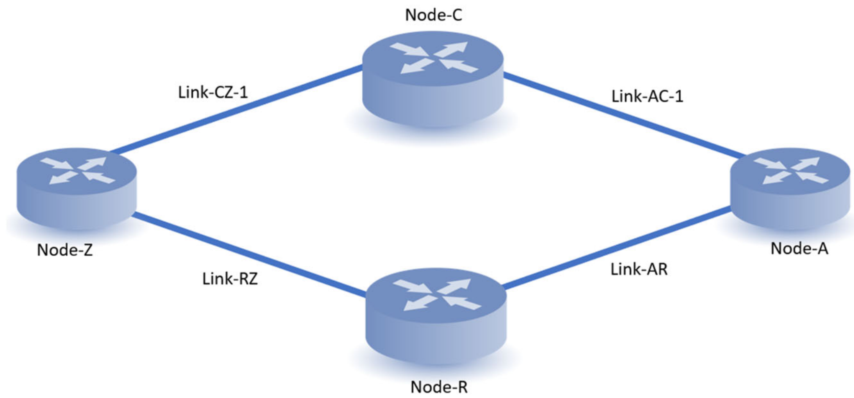

Figure 5B: Trade-Off Network Operational Focus Mode

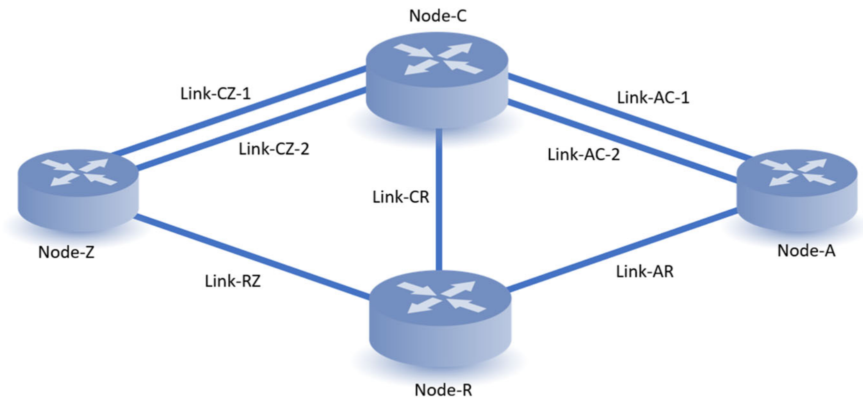

Figure 5C: Full-On Network Operational Focus Mode

While the above-described planes, mappings, and modes may appear to be a case of overengineering for the four-node network of the instant example, it is through that example that the programmatic aspects and the scalability of the presented techniques may be seen and the potential application of those techniques to a very large network may be appreciated. In a sense, modifications within the above-described flexible structures are somewhat analogous to changing a mode in a mobile phone.

To summarize everything that has been presented thus far, and to provide a complete overview of aspects of the presented techniques, consider the exemplary arrangement that is depicted in Figure 6, below.

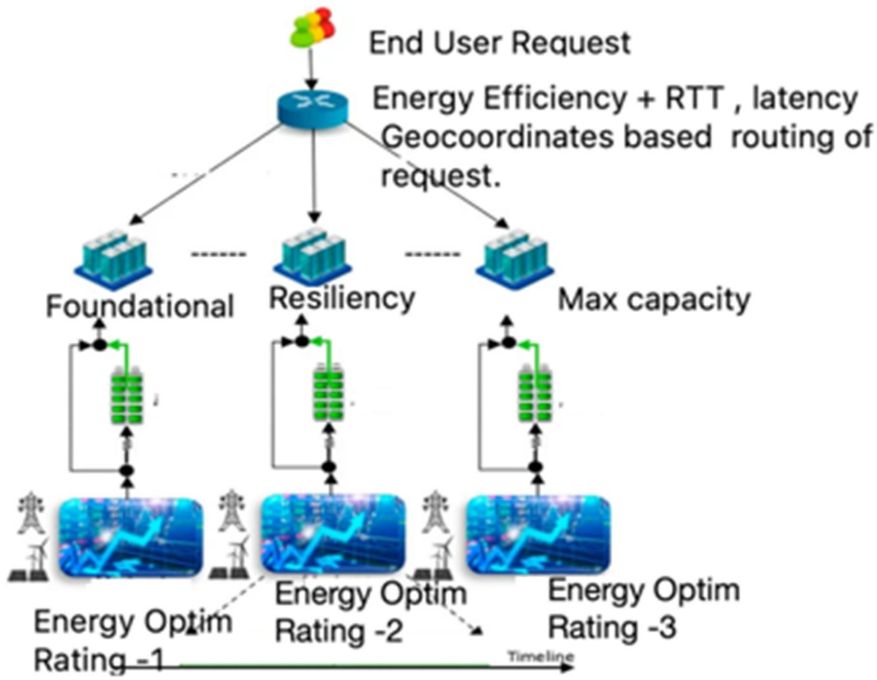

Figure 6: Exemplary Arrangement

Figure 6, above, along with Table 1, above, may be used to highlight several of the novel elements of the presented techniques. First, sub-topological planes support the assignment of key network elements and sub-elements to different planes, thus enabling an identification of the most optimal topological nodes for the routing of incoming traffic (as expressed through the Table 1 mappings). Second, through network operational focus modes a range of different topologies (including the exemplary Foundational network topology, Resilient traffic forwarding topology, and Maximum Capacity traffic handling network topology that were illustrated above) may be defined. Third, through mappings, depending upon the mapping plane that is selected a separate energy optimization profile may be applied to derive the utility billing costs, a carbon dioxide equivalent (CO_2e) usage value, etc. The above-described artifacts may be used to, for example, support the dynamic selection of a mode for the forwarding of incoming network traffic.

According to the presented techniques, a number of different advanced operations are possible beyond the different capabilities that were previously described. For instance, in the above-described illustrative example it may be the case that Node-R (which may benefit from renewable energy sources) is more “sustainable” than Node-C (which may be associated with carbon-based energy sources). Such an arrangement is depicted in Figure 7, below.

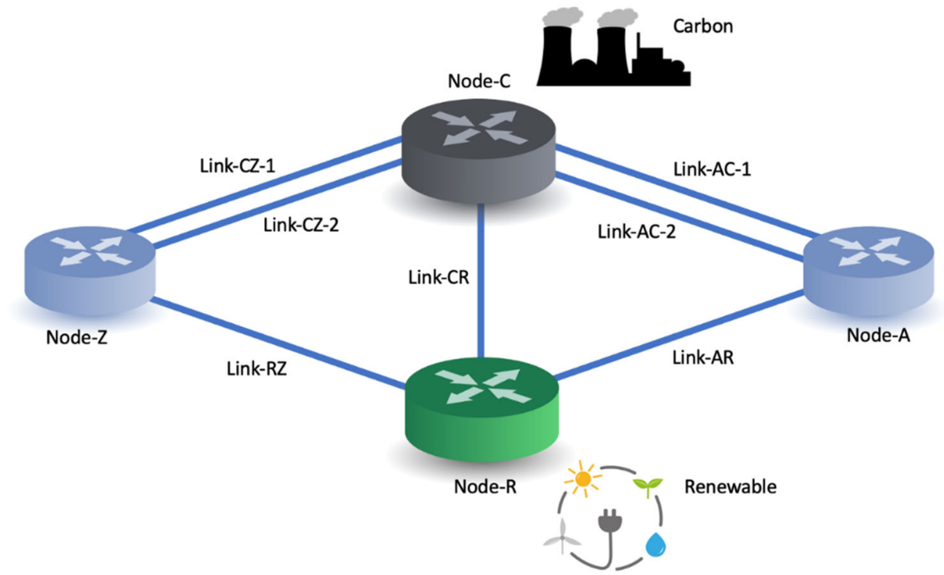

Figure 7: Illustrative Sustainability Arrangement

Under the arrangement that was presented in Figure 7, above, there are two use cases that are of particular interest.

A first use case encompasses a constant (e.g., traffic) demand that is coupled with a variable carbon intensity or renewability percentage. Under this use case, different network elements may shift from one sub-topological plane to another (as expressed through the mappings in Table 1, above) resulting in different routing selections. Figure 8, below, illustrates elements of such a variability.

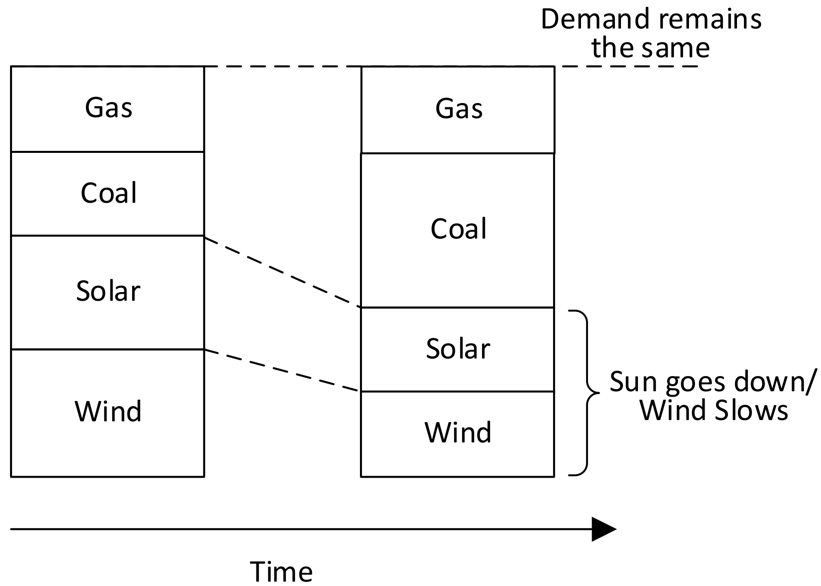

Figure 8: First Use Case

A second use case encompasses variable (e.g., traffic) demand (that may decrease or increase) that is coupled with a constant carbon intensity or renewability percentage. Under this use case, one or more sub-topological planes may be added to, or removed from, the network topology (as expressed through the mappings in Table 1, above) resulting in different routing selections. Figure 9, below, illustrates elements of this type of variability.

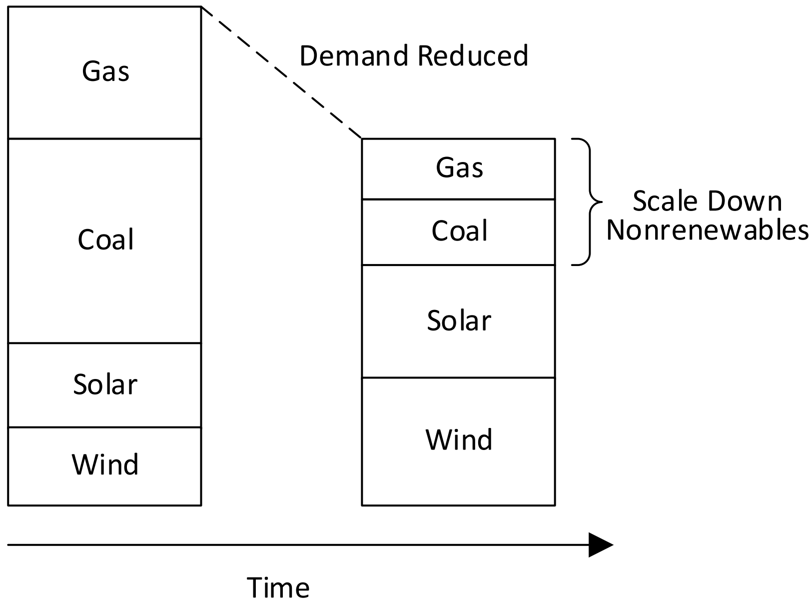

Figure 9: Second Use Case

While the above narrative employed a paradigm under which a network element was, in a binary fashion, either all of the way "in" use or all of the way "out" of use, it is important to note that the presented techniques may be extended in a straightforward fashion to encompass "gray" areas that reside somewhere between "in" and "out." Among other things, various network elements and sub-elements may be selectively tuned, one particular example of which is presented in Table 4, below.

Table 4: Exemplary Tuning

Topological Element	Sub-Topological Planes		
	Foundational	**Resiliency**	**Maximum Capacity**
Node-C → CPU	X (Underclock CPU)	X (CPU Clock Speed Set to Spec)	X (Overclock CPU)

The network element that is to be tuned is identified in Table 4, above, as a central processing unit (CPU) in Node-C (i.e., the topological element "Node-C → CPU"). As indicated in Figure 7, above, this is the node that is associated with carbon-based energy sources and, consequently, is a node that may benefit from optimization. In this instance, the tuning (of this network element) involves adjusting the CPU's clock speed, through underclocking or overclocking, to optimize for power efficiency and performance.

Under another possible example, a link aggregation (LAG) facility may be the topological element (i.e., the network element that is to be tuned) and the tuning may encompass changing a Max-LAG-Links attribute to allow for, perhaps, two links in a Foundational sub-topological plane, three links in a Resiliency sub-topological plane, and four links in a Maximum Capacity sub-topological plane (referring back to the exemplary planes that were presented in Figure 3, above).

It is important to note that the presented techniques may be employed in any number of ways beyond the network traffic routing scenario that was outlined in the preceding narrative. For example, the specific decomposition of planes and modes makes the techniques ideal for modeling, whether it be for network planning and capacity planning or as applied to a digital twin.

As described and illustrated above, through the presented techniques network-wide sustainability network operational focus modes may be defined. Such modes may encompass any number of elements including, for example, all power usage, a turning off of (optics, unused, etc.) ports, an underclocking of a CPU, a minimum power level, etc. Such modes may then be matched to TCVTs, which are like a superset of TVR but with a more versatile implementation. Then, different modes may be employed in the support of the graceful routing of network traffic (e.g., at a certain time at night use mode three, if the context is such that traffic exceeds a threshold use mode 1, etc.).

In summary, techniques have been presented herein that leverage the concept of TVR to create TCVTs that offer a scalable and versatile solution for supporting a proportional response to changes in a network's traffic levels, allowing a network operator to maximize sustainability gains in a network having variable, tidal, and periodic traffic. Aspects of the presented techniques encompass sub-topological planes (which can be made available to a topology as a function of time), network operational focus modes (which employ such planes to create objective-optimized topologies), and mappings between the two. The techniques allow an optimal set of topological elements to be identified based on different variables including, for example, a traffic demand and a renewable energy makeup (e.g., a carbon intensity). By hiding all of the complexity from a user, the techniques offer a simplified user experience through which such a user need only select different network operational focus modes to manage very complex outcomes.