Framework for analyzing feasibility of Internet protocols

Tapio Levä, Henna Suomi

Aalto University, Department of Communications and Networking

P.O. Box 13000, 00076 AALTO, Finland

[tapio.leva; henna.suomi]@aalto.fi

ABSTRACT: A multitude of Internet protocols are developed in the Internet Engineering Task Force to solve the challenges with the existing protocols and to fulfill the requirements of emerging application areas. However, most of them fail to achieve their goals due to limited adoption. A significant reason for non-adoption seems to be that the potential adopters' incentives for adoption are not understood and taken into account during the protocol development. This paper addresses the problem by introducing a conceptual framework for analyzing the techno-economic feasibility of Internet protocols already during their development. The framework is based on the experiences collected during several protocol case studies and an extensive literature review. It focuses on analyzing the economic incentives of the relevant stakeholders and also takes into account the deployment environment including the competing solutions. After introducing the framework, the paper summarizes the deployment challenges and related solutions of the Multipath TCP and Host Identity Protocol cases. The suggested framework can help protocol developers to identify the potential deployment challenges of emerging protocols and thus increase the likelihood of adoption. Moreover, potential adopters can use the framework as a supporting tool for making adoption decisions.

Keywords: Techno-economic analysis, protocol adoption, diffusion, methodology, Multipath TCP, Host Identity Protocol

1 Introduction

The Internet standardization community is very active in producing new Internet protocols as a response to the challenges with the existing protocols and the requirements of emerging application areas. For example, the Internet Engineering Task Force (IETF) has 127 active working groups that produced 337 working documents called as Request for Comments (RFC) during 2012 alone [1]. However, most of the new protocols never end up in use in the originally envisioned scale and scope [2]. Several reasons have been raised for explaining the lack of adoption, such as middleboxes blocking the traffic [2], difficulties in achieving critical mass [3], and lack of authorities that could mandate adoption [4]. According to the authors' experience, one reason for the feasibility problems is that the protocol developers have insufficient understanding of the stakeholders' economic incentives to adopt a protocol, and thus end up designing protocols based on false or inaccurate assumptions. The IETF community has addressed this problem by identifying design principles [5,6] and protocol success factors [7] that should facilitate adoption. However, the general design principles are not sufficient to guarantee the feasibility of a protocol since they neglect the special characteristics of each protocol and mainly cover technical deployment issues leaving aside the economic perspective.

The understanding of the economic factors affecting the feasibility of Internet protocols has increased gradually in the recent years as the theories and methods of innovation diffusion research have been applied in Internet protocol case studies, such as the retrospective studies of DNSSEC [3] and IPv6 [8,9]. However, these studies have a couple of limitations from our perspective. Firstly, they have been conducted separately from the protocol development after the protocol has already been standardized. Thus, the identified feasibility challenges cannot be taken into account in the protocol design. Secondly, they focus only on the feasibility for the potential end users of the protocol, although the success of the protocol also depends on other stakeholders, such as operating system (OS) vendors implementing and including the protocol in their operating systems.

To overcome the shortcomings of generic design principles and retrospective protocol case studies, this paper introduces an accessible and flexible framework for studying the feasibility of Internet protocols during their development, which is originally proposed in our recent paper [10]. Compared to the earlier studies, the framework takes a wider perspective by covering also the other critical steps in protocol deployment. Protocol deployment is defined as *a process during which a protocol is advanced from the first specification into actual use on the Internet*. The process includes steps such as implementation, installation, and adoption of the protocol and the related technical components. This extension is relevant since the protocol deployment needs to be feasible not only to the adopters, such as the end users of the protocol, but also to the other stakeholders participating in protocol deployment.

The framework is based on our experiences from multiple protocol case studies, including Multipath TCP (MPTCP), Mobile IP (MIP), Host Identity Protocol (HIP), Constrained Application Protocol (CoAP) and Locator/Identifier Separation Protocol (LISP). In addition, a literature review has been conducted to acquire a comprehensive understanding of factors that contribute to the protocol adoption. The most influential studies, which have affected the formulation of the framework, include the seminal work of Rogers on diffusion of innovations [11] and the theory of network effects [12]. Besides the authors' own contributions, the protocol case studies, such as [8][9][13], and the RFC 5218 of protocol success factors [7] have inspired the development of the framework. Compared to the case studies, the methodological efforts for studying protocol feasibility have been few but the contributions of Eardley et al. [14] and Kalogiros et al. [15] have been considered in the framework construction. For more extensive literature review, please refer to [10].

By proposing this framework we argue that the techno-economic analysis should gain momentum in the protocol development in order to increase the likelihood of protocol adoption. The techno-economic analysis should be practiced systematically from the beginning of the protocol development and span throughout different phases of protocol deployment. The framework aims to translate the technical design and protocol features into actual costs and benefits for the stakeholders. As such, it is targeted to protocol developers with limited knowledge of economics and should foster their cross-disciplinary thinking.

2 Framework

Studying the techno-economic feasibility of a protocol under development is a challenging task, which culminates in understanding whether the relevant stakeholders – including both the actual end users and other stakeholders in the value network – have incentives for participating in protocol deployment. In order to answer this question, this section describes a framework consisting of six analysis steps as illustrated in Figure 1. Each step comprises a set of questions, the answers of which form the input for the next step.

Protocol specification works as the starting point for the framework. It describes the technical design of the protocol that has been produced in the protocol design process as a solution to an envisioned problem or need. The specification does not have to be finalized; already a draft version is enough for conducting useful analysis. Steps 1-4 scope the techno-economic feasibility analysis by defining the use case, technical architecture, value network and deployment environment, respectively. Then, step 5 studies the feasibility of the protocol from the perspectives of all relevant stakeholders in order to identify deployment challenges of the protocol. Finally, step 6 suggests solutions to the identified challenges.

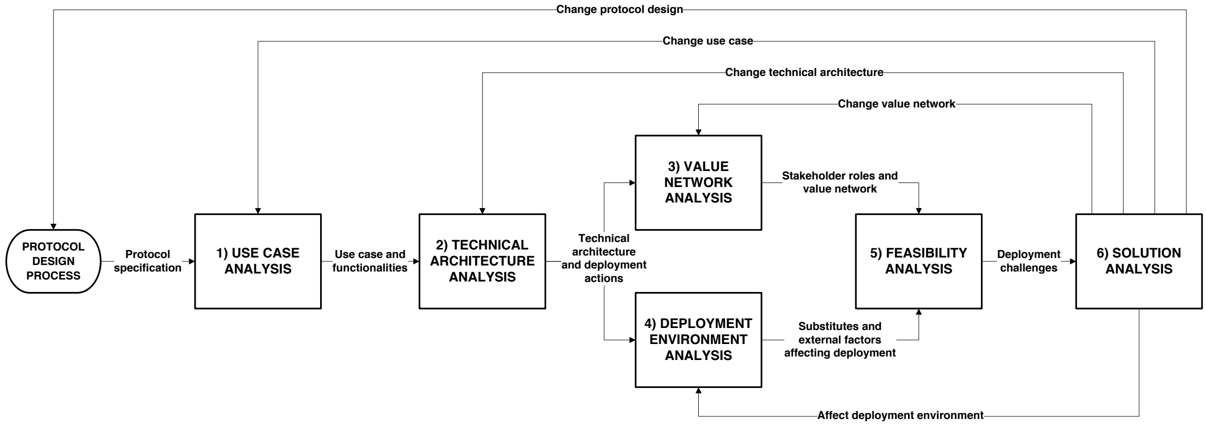

Figure 1. Framework for analyzing the techno-economic feasibility of Internet protocols

A multitude of supporting tools can be used for answering the questions in each step. The original paper [10] lists a bunch of example tools for steps 2-5 and these tools are introduced in more detail in Section 4 of that paper. Even though the tools give structure to the analysis and help to visualize the findings, the successful usage of the framework does not necessarily require their usage. However, familiarizing oneself with the tools improves understanding of the framework.

2.1 Step 1: Use case analysis

The use case analysis describes the purpose and functionalities of the protocol and translates them into potential use cases. Since the protocol may enable multiple use cases that differ significantly from each other in their technical architecture, value network and deployment environment, explicit specification of the use case is required. The description of a use case should include the selected functionality of the protocol, which is supposed to turn into the benefits for different stakeholders in later steps.

If the protocol enables multiple use cases, the complete techno-economic feasibility analysis requires a separate analysis for each use case. Therefore, use cases should be prioritized according to their attractiveness. The most attractive use case may have the highest expected demand or least competition from other solutions. When multiple use cases are analyzed, the framework can help to separate the more promising use cases from the less promising ones.

Key questions:

- ❓ What are the purpose and the functionalities of the protocol?
- ❓ What is the use case to be studied?

2.2 Step 2: Technical architecture analysis

Technical architecture analysis describes the technical architecture and deployment actions of the use case. Deployment actions refer to all the actions that need to be taken in order to advance the protocol from the specifications into actual use on the Internet. They can relate, e.g., to implementing, installing, operating, or adopting the protocol and the related technical components. Identifying these actions serves the feasibility analysis as they incur costs that the involved stakeholders have to bear if they decide to participate in protocol deployment.

Often the technical design and the chosen use case allow multiple technical architectures with different deployment actions. A typical example with Internet protocols is an alternative to deploy a protocol either in end-hosts or in a proxy in the middle of the communication path. Similarly, a protocol can be implemented in the OS kernel, as application layer middleware, or directly in applications. The framework does not mandate the choice of a single deployment scenario, which allows a comparative analysis of multiple technical architectures.

Key questions and tools:

- What is the technical architecture to be studied?
- What are the required deployment actions in the chosen technical architecture?

2.3 Step 3: Value network analysis

Value network analysis maps the deployment actions to the stakeholders responsible for taking them. This translates into identifying the relevant stakeholders and their roles in protocol deployment. In this paper, a stakeholder is defined as *any group or individual who can affect or is affected by the deployment of the protocol*. This covers both the stakeholders directly participating on protocol deployment, and stakeholders, such as regulators, that can indirectly affect the success of the protocol by either facilitating or hindering deployment.

Besides mapping the deployment actions to the stakeholders, the value network analysis defines how the service enabled by the protocol is provided. In practice, this means identifying how the goods and services, money or intangible benefits are exchanged between the stakeholders. This information is used in step 5 to compare the costs and benefits and to analyze the incentives of each stakeholder to participate in protocol deployment. Similarly to technical architectures, multiple value networks are typically possible. For example, a vertically integrated stakeholder might take the responsibility of all the deployment actions, or the actions could be divided horizontally among multiple stakeholders.

Key questions:

- Which are the relevant stakeholders in the chosen use case?
- How are the deployment actions allocated to the stakeholders?
- What is the value network of the service provided in the chosen use case?

2.4 Step 4: Deployment environment analysis

As protocols are rarely deployed in a void, understanding the environment where the protocol is to be deployed is essential. Deployment environment analysis can be divided into the analysis of the substitutes of the protocol, and the wider environmental analysis. In this step the analysis is technology-centric, as against the stakeholder-centric analysis of steps 3 and 5.

The analysis of the substitutes starts with their identification. Substitutes include both the incumbent solutions and the other new solutions under development. In addition to other protocols at the same or different layer of the protocol stack, substitutes can be, for example application-specific solutions. The use case definition helps in deciding, which solutions truly solve the same problem, i.e., can substitute the protocol under study. After the identification, performance and deployment status of the substitutes should be compared against the protocol under study. This helps in deciding which substitutes are included, when the relative advantage of the protocol is analyzed from the stakeholder-centric perspective in step 5.

The wider environmental analysis incorporating the political, economic, social, and technical domains helps in identifying the external factors affecting the feasibility of the protocol. Additionally, this step can include exploring the possible evolution paths of the deployment environment in order to understand the trends that are favorable and non-favorable for the protocol deployment. This is especially important in the early phases of the protocol development when the deployment is expected to happen only in the distant future.

Key questions:

- ❓ What are the relevant substitutes of the protocol in the use case and how do they compare against it?
- ❓ What are the relevant external factors affecting feasibility of the protocol and how can the deployment environment evolve in the future?

2.5 Step 5: Feasibility analysis

After steps 1-4 have scoped the study, step 5 analyses the feasibility of the protocol by evaluating if the relevant stakeholders have incentives to participate in protocol deployment. In practice, this translates into comparing the costs and benefits of the protocol for each relevant stakeholder. Therefore, the analysis needs to take into account all the stakeholders identified in step 3 and the substitutes and other relevant factors identified in step 4.

The fundamental question in protocol feasibility is whether a real need for the protocol exists in the market. This is an important point of analysis since the problem that the protocol solves may not correspond to the demand of the stakeholders. Therefore, the potential adopters may not see any value in the protocol if they are happy with their current (good enough) solutions, and the perceived benefit, translating to the willingness to pay, is close to zero.

Assuming that the demand for the protocol exists, the minimum condition for the feasibility of the protocol is that its benefits cover its costs, or, in other words, its utility is positive for all the relevant stakeholders. Although the protocol would introduce a positive utility for each stakeholder, it should also have relative advantage over its substitutes. The separation of studying the feasibility of a protocol, first independently of, and then in relation to, substitutes may be challenging. Therefore, the utility of the protocol is often studied immediately in comparison to its substitutes.

The static, separate analysis of each stakeholder is not sufficient, because the costs and benefits of the protocol often depend dynamically on the number of adopters. Therefore, studying the impact of network effects, both between the similar and different types of adopters, is essential. Typical questions to ask are *do the early adopters have incentives to adopt* and *what is the critical adopter mass after which the benefits exceed the costs*.

Estimating the values of the cost and the benefit components may be challenging, especially during the early phases of the protocol development when the level of uncertainty is high. This presents a challenge to feasibility analysis but does not prevent it. The main objective of feasibility analysis is namely the identification of the deployment challenges of the protocol, which can often be done already based on the qualitative analysis. The challenges typically result from the relevant stakeholders' lack of incentives to participate in protocol deployment.

Key questions and tools:

- ❓ Does the protocol demonstrate positive net benefits for all the relevant stakeholders?
- ❓ How do network effects impact on the formation of costs and benefits?
- ❓ What are the deployment challenges of the protocol?

2.6 Step 6: Solution analysis

After the potential deployment challenges of the protocol have been identified, the protocol developers or other advocates should consider how the challenges could be solved. Basically, five high-level solutions exist: 1) changing protocol design, 2) changing use case, 3) changing technical architecture, 4) changing value network, and 5) affecting deployment environment. The choice of the solution depends on the problem at hand, the maturity of the protocol, and the power of the protocol advocates to impact on the aforementioned matters.

Firstly, a fundamental problem in the protocol design – such as the lack of backwards compatibility, performance issues, or problems with middlebox traversal – may require changes to the protocol design. These kinds of issues should be identified as early as possible because protocol design can be easily changed only prior to the final standard is accepted. Secondly, a protocol may not be sufficiently feasible in the selected use case due to, for example, too hard competition from substitutes or disinterest of an essential stakeholder. In this case, the protocol may need to be scoped again for other use cases. As a result, the framework can help to separate the promising use cases from the non-promising ones.

Thirdly, technical architecture can often be changed without changing the protocol design itself. As a result, some of the problematic deployment actions can possibly be eliminated or replaced with easier actions. For example, a functionality originally implemented in a central server could be distributed to multiple locations to improve the performance of the service. Fourthly, a typical challenge with Internet protocols is the misalignment of costs and benefits, which can possibly be solved by payments or other business agreements between the participating stakeholders. Incentive mechanisms, such as bundling of complement products and monetary subsidies, or reallocation of the value network roles could also be used to facilitate protocol deployment in cases where the business case is not sufficiently attractive to some stakeholders. The fewer stakeholders are involved, the less expensive coordination is required.

Finally, affecting the deployment environment may be used to improve the feasibility of the protocol. This may include actions like lobbying the politicians responsible for legal decisions in favor of the emerging protocol or creation of alliances supporting the protocol. However, affecting the deployment environment is a challenging strategy for facilitating the protocol deployment and the other solutions introduced above are presumably more effective.

Before implementing the solutions, their impact should be analyzed by going through the framework again. In general, the framework should be used iteratively as long as all the potential feasibility challenges have been solved or they are deemed to be unsolvable.

Key questions:

- What are the potential solutions to the identified deployment challenges?
- How would the implementation of the potential solutions affect the feasibility of the protocol?

3 Protocol case studies

In order to demonstrate the potential of the framework, we summarize the results from applying the framework to two protocol cases: Multipath TCP and Host Identity protocol. The presentation focuses on the deployment challenges and solutions identified in steps 5 and 6 of the framework, whereas the other steps have been covered in the referred papers.

3.1 Multipath TCP

Multipath TCP (MPTCP) [17] is an extension to normal TCP that exploits multiple paths between hosts and aims for better utilization of network resources. Improved resiliency and throughput are the main benefits of MPTCP. The techno-economic feasibility of MPTCP has been studied in our earlier MPTCP studies [18-22] that have covered different steps of the framework. The full application of the framework on MPTCP is demonstrated in [10].

3.1.1 Deployment challenges

Based on the earlier studies three deployment challenges for MPTCP can be highlighted here:

#1. Firstly, the capacity in networks is increasing all the time along with new radio technologies, such as LTE, but also with fiber deployments. If *the capacity increase in single-path communication is sufficient for end user applications* the performance improvement expected by MPTCP deployment is not needed [22]. In addition, moderate growth of size and demand of content decreases the attractiveness of MPTCP.

#2. Secondly, OS vendors may perceive the costs to implement and maintain MPTCP code and provide support for end users larger than the revenue it brings as an additional OS feature [19]. Monetizing the new multipath feature in the OS may be challenging for the vendors and therefore other motives such as competitive pressure should be high enough for them to implement MPTCP.

#3. Thirdly, content providers may not see the incentives to start providing MPTCP services because there are no consumers with MPTCP support, while consumers do not adopt MPTCP due to lack of services using it [21]. This is called the *chicken-and-egg problem*.

3.1.2 Solutions to the challenges

Potential solutions for the identified deployment challenges can be identified as follows. The challenges that each solution answers to are identified in brackets.

Application implementation: The participation of the OS vendors would not be required if the functionalities of MPTCP would be implemented directly into applications or as application-layer middleware. New applications having high performance requirements could also accelerate adoption of MPTCP. (#1, #2)

Lobbying: Since incentivizing the OS vendors to implement MPTCP is crucial, lobbying could be one solution to increase the knowledge of MPTCP and its benefits among OS vendors. (#2)

Open source implementation of MPTCP: Implementing MPTCP in an open source OS, such as Linux, could be used to create competitive pressure and demonstrate the benefits and feasibility of MPTCP for the vendors of commercial operating systems. (#2)

Both ends in one hand: A simple way to solve the chicken-egg problem between the consumers and content providers is to change the value network so that a single stakeholder (e.g., Apple, Nokia, Google) controls the operating systems on both mobile devices and on the content servers. (#3)

Proxy implementation: If the diffusion of MPTCP to consumer devices is too slow, MPTCP could be implemented in an ISP-provided proxy. This change in both technical architecture and value network would increase the role of ISPs and introduce new incentives to them. (#3)

3.2 Host identity protocol

The Host Identity Protocol (HIP) [23] proposes a persistent identity for a networking device to identify it independently of its location. In brief, HIP 1) secures network data flows of applications, 2) improves IPv6 interoperability, 3) supports NAT traversal, and enables 4) mobility and 5) multihoming. Despite significant R&D efforts and publication of the experimental standard already in 2008, the deployment of HIP has been minimal. Therefore, the development version of the framework was applied in [24] for studying the feasibility of Host Identity Protocol (HIP) based on an extensive interview study covering 19 experts.

3.2.1 Deployment challenges

The six main reasons why HIP has not been widely deployed yet are:

#1. Most importantly, the demand for the functionalities of HIP has been low.

Where demand would have existed, substitutes (MIP, IKE, TLS) have been favored because:

#2. Substitutes were earlier on the market,
#3. Substitutes have (perceived) relative advantage due to some design choices of HIP,
#4. HIP lacks early adopter benefits necessitating costly coordination,
#5. People have misconceptions about the deployability of HIP, and
#6. The research-mindedness of HIP developers has lead to strategic mistakes and non-optimal design choices from the perspective of deployment.

In addition to lower than anticipated demand for mobility and security protocols, the demand problem (#1) is caused because HIP solves multiple interrelated problems at the same time when often a point solution to a single problem suffices, performs better, and is easier to deploy (#3). Consequently, the approach taken by RTCWEB and Apple's Back-to-my-Mac of combining multiple existing protocols to create new solutions might be more feasible.

Transparency to applications is another design problem of HIP (#3), because it may cause problems if applications pass host identifiers to HIP-incapable hosts (known as the referral problem). More importantly, applications often want to influence, control or at least be aware of their traffic because they have better knowledge over transport and application state, and user requirements, than network layer protocols. Therefore, allowing applications to control lower layer protocols through an API seems like an important requirement for their success.

HIP also suffers from the myth (#5) that its deployment would require changes to the OS kernels, which have high inertia for change due to long OS update cycles and OS vendors' conservativeness on what to include in their operating systems (#4). Even though the conceptual location of HIP between transport and network layers implies this as the TCP/IP stack is typically implemented in the kernel, HIP can actually be implemented in the userspace as all HIP implementations demonstrate. This was not the only myth among the interviewees, which demonstrates the impact of people's conception on protocols' success.

3.2.2 Solutions to the challenges

Similarly to the MPTCP case, the potential solutions to the identified deployment challenges are identified below. The challenges that each solution answers to are identified in brackets.

Focus on the most promising use cases: Instead of applying HIP to every possible purpose, the developers should focus on the problems and use cases with the highest demand. In other words, depth-first should be preferred over breadth-first. The most promising use cases were seen to be found from the private deployment scenarios, such as military, public safety and industrial control systems, in which the deployment is controlled by a single stakeholder and the communications remains in the private network. (#1, #3)

Co-deployment with applications: Co-deployment of HIP with an application (e.g., integrated into a web browser) or as application-layer middleware would allow bypassing the OS vendors that are not currently interested in implementing HIP. This strategy would allow partial deployment for applications. A related, supporting action would be to enable better control to applications by improving the APIs between HIP and applications. (#3, #4)

(Company-driven) education and marketing: Education is needed to correct the myths caused by the poor real-life deployability in the beginning of HIP development. The ongoing transformation of HIP RFCs from experimental to standards track is one effort in this path. A successful, company-driven real life deployment on the public Internet could be even a better way to spread the information and increase the credibility of HIP. (#5, #6)

4 Discussion

With the proposed framework we argue that the techno-economic analysis should gain momentum in order to improve the success rate of protocols, and thus the efficiency of the protocol development. The analysis should be practiced systematically from the beginning of the protocol development and span throughout the different steps of protocol deployment. The cornerstone of the analysis is the proper understanding of the protocols' technical design, features, and performance, which are then translated into the costs and benefits in order to analyze the stakeholders' incentives for participating in protocol deployment. Also the constantly changing deployment environment including the substitute solutions and other external factors need to be taken into account due to their large impact on the feasibility of the protocols. This kind of systematic and iterative analysis allows the early identification of the deployment challenges and related solutions, which facilitates protocol deployment.

The framework deserves also critical examination concerning its limitations and usefulness:

- Firstly, the framework is heavily based on a limited number of protocol case studies conducted by the authors, which calls for a further validation by wider audience. This is made possible through the publication of the framework.
- Secondly, the efficiency of the framework, and the techno-economic analysis in general, is difficult to prove mathematically due to the heterogeneity of the protocol cases. However, the increasing role of techno-economic analysis in the European commission research projects supports the notion of its potential.
- Thirdly, one could argue that many of the challenges could be identified without the framework by using the public and tacit knowledge of typical deployment problems. This may be possible for the seasoned protocol developers familiar both with the technology and the rules of business, even though the poor track record of IETF standards does support this. In any case, the framework gives an opportunity also for the less experienced developers to inspect the economic feasibility of their solutions.
- Fourthly, the open and conceptual nature of the framework motivated by the heterogeneity of the protocols makes it rather abstract and may lead to trivial findings, in case the analysis is made superficially. To avoid this risk, the appliers should have some experience on Internet economics and market dynamics. Typically, a more elaborate analysis can be conducted if the developer of the analyzed protocol joins the feasibility study with the support of people with business-oriented background.
- Fifthly, the feasibility analysis may fail to predict the outcome of the protocol deployment, because some companies may act irrationally and continue advancing the protocol in order to sell more products and show their technical capabilities, although demand for the protocol would be low. In addition, sometimes the availability of technologies just creates demand, which is hard to understand beforehand.

Two target groups should be interested in using the framework. Firstly, improved understanding of the stakeholders' incentives helps *protocol developers* to avoid design decisions leading to non-deployment and to take strategic actions to facilitate deployment. Secondly, *potential adopters* can make more informed adoption decisions if they understand, whether the other stakeholders are interested in doing their part. Organizations belonging to these groups participate in the IETF standardization, and therefore, researchers and engineers in the IETF could be the first potential users of the framework. Some of the working groups in the IETF have already been studying the use cases and deployment considerations of certain protocols, but our framework provides a more systematic baseline for such studies. In the best case, the framework could construct guidelines for the *deployment considerations* that could be made a similar, mandatory part of an RFC as the *security considerations* are.

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