

# Congestion Control Principles for CoAP draft-bormann-core-congestion-control-00pre

## Abstract

The CoAP protocol needs to be implemented in such a way that it does not cause persistent congestion on the network it uses. Congestion control is a complex issue — the proper rationale for the congestion control mechanisms chosen in CoAP is probably more material than the CoAP protocol specification itself. This informational document attempts to pull out the background material and more extensive considerations behind the CoAP congestion control mechanisms, while leaving the basic MUSTs and MUST NOTs in the main spec.

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## 1. Introduction

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With few exceptions, it is simply incompetent to build an implementation of a packet-based protocol without considering congestion control. Unfortunately, detailed, evidence-based knowledge about congestion control is limited to a small group of people. It has become customary for these to try to encode their knowledge into the protocol definitions, in an attempt to replace competence by conformance.

This has worked relatively well for TCP, not the least because the art of TCP implementation is itself limited to a rather small group of experts, which over the years often have acquired some knowledge of congestion control principles. Conversely, application developers are a much larger, much more diverse group. Giving congestion-unaware developers UDP sockets that are not protected by TCP's congestion control may lead to disasters.

With this background, an application protocol that is threatening to be widely deployed and does not rely on the built-in congestion control properties of TCP presents a serious worry.

This document attempts to present a more extensive rationale for CoAP's congestion control design. This rationale is not included in [\[I-D.ietf-core-coap\]](#) or [\[I-D.ietf-core-observe\]](#) as the specification is threatening to become too long with all the rationale and implementation considerations discussion already included. While the present document discusses normative statements, it is not intended to supplement or replace the normative statements in [\[I-D.ietf-core-coap\]](#) and [\[I-D.ietf-core-observe\]](#), but just to provide additional explanation.

((Editorial note: the mandates discussed here partially still need to make it into the next version of [\[I-D.ietf-core-coap\]](#)...))

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### 1.1. Terminology

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The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be

interpreted as described in **[RFC2119]** when they appear in ALL CAPS. These words may also appear in this document in lower case as plain English words, absent their normative meanings.

(Note that this document is itself informational, but it is discussing normative statements.)

The term “byte” is used in its now customary sense as a synonym for “octet”.

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## 1.2. Objectives

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The objectives of adding congestion control to the CoAP protocol specification can be on two different levels.

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### 1.2.1. TCP-Friendliness

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Much of the knowledge that the IETF has accumulated on congestion control focuses on not being worse than its flagship transport protocol, TCP, and being “fair” to instances of TCP competing for capacity. Since fairness is not really a well-defined term, we reduce it to “friendliness”.

One objective of this document is to discuss how CoAP can be employed in a TCP-friendly way, and what are the minimum mandates the protocol needs to make in order to ensure this for reasonable applications.

(Note that TCP itself is not TCP-friendly when abused, e.g., when opening 10000 connections in close succession; so there will be no attempt to stay TCP-friendly when CoAP is abused, either.)

Conclusion:

CoAP needs to be TCP-friendly, but probably not more so than TCP itself.

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### 1.2.2. Actually working well

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Making sure that the network continues to work well in the presence of a strong deployment of active CoAP endpoints is a much harder objective to achieve. There is only limited knowledge about the characteristics of the constrained node/networks CoAP will be used in. They might exhibit congestion in surprising ways.

It may turn out the collected wisdom that has been derived from TCP deployment experience in the mostly browser-oriented Internet does not transfer to the Internet of Things, and that we need to invent new mechanisms for the latter.

But this is research.

Imposing the need for a completed solution that meets requirements entirely unknown at this time would be an instance of the Fallacy of Perfection **[GF]**.

We will need to accumulate additional knowledge, on a research basis, and with experience coming in from larger CoAP deployments. One likely outcome is that constrained node/networks will simply continue to evolve to be able to cope with TCP and CoAP.

Conclusion:

For now, we will focus on staying safe where TCP would have stayed safe.

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## 2. Input

The word “congestion” occurs more than a hundred times in 1id-abstracts.txt, indicating that there is a lot of documents under construction that might become relevant to this document. We select a few existing documents here and pick up the salient points.

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### 2.1. RFC 2914

**[RFC2914]**, “Congestion Control Principles”, is the BCP that lays out the basic principles for congestion control in the Internet. While it does allude to non-TCP protocols, it mainly focuses on TCP and TCP-like behavior.

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### 2.2. RFC 5405

**[RFC5405]**, “Unicast UDP Usage Guidelines for Application Designers”, makes additional points for the usage of UDP. It is also a BCP document. Its considerations have mostly been made without looking at specific application protocols, and with a view to guiding application protocol developers towards congestion-controlled transport protocols (which is unfortunately not an appropriate choice for CoAP). It does consider the case of low data-volume applications (section 3.1.2 is therefore the most relevant section for this document). It clearly needs to be interpreted intelligently in order to arrive at congestion control guidelines for a new application protocol. E.g., it recommends:

Applications that at any time exchange only a small number of UDP datagrams with a destination SHOULD still control their transmission behavior by not sending on average more than one UDP datagram per round-trip time (RTT) to a destination.

Instead, a CoAP client that does receive a response without the need for a retransmission should be able to send an ensuing request right away, without the need to do any such rate control.

While **[RFC5405]** does provide a good set of “don’t forget” points, some of its requirements appear to attempt to err on the side of caution, without regards to the specific characteristics of an application. Fortunately, these requirements are often phrased as a SHOULD, so it is possible to explain when and why they should not be heeded.

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### 2.3. draft-eggert-core-congestion-control

**[I-D.eggert-core-congestion-control]**, “Congestion Control for the Constrained Application Protocol (CoAP)”, was the original document that led to CoAP’s congestion control design. This document provides good historical context and should be read in conjunction with the present document. However, the “credit-based” mechanism proposed in its section 3.2 is probably too complicated to be implemented in constrained nodes; CoAP now uses a simpler algorithm that uses the information the implementation already has to keep (i.e., it is based on limiting the outstanding exchanges).

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## 3. coap-09 Congestion Control Principles

CoAP is a protocol that attempts to minimize the complexity of its implementation. It is mainly intended for interactions that are not really flow-shaped, so traditional congestion control mechanisms simply do not have useful information to work on.

Basic CoAP **[I-D.ietf-core-coap]** uses a strict lock-step protocol for its requests and responses (both on the reliability layer with CON/ACK and one level higher with requests and responses), with exponential back-off in case of non-delivery. The initial timeout is dithered between 2 and 3 seconds and grows up to between 32 and 48 seconds.

This is inherently TCP-friendly, similar to the way protocols like DNS operate.

**[I-D.ietf-core-coap]** goes on to require:

In order not to cause congestion, Clients (including proxies) SHOULD strictly limit the number of simultaneous outstanding interactions that they maintain to a given server (including proxies). An outstanding interaction is either a CON for which an ACK has not yet been received but is still expected (message layer) or a request for which a response has not yet been received but is still expected (which may both occur at the same time, counting as one outstanding interaction). A good value for this limit is the number 1. (Note that **[RFC2616]**, in trying to achieve a similar objective, did specify a specific number of simultaneous connections as a ceiling. While revising **[RFC2616]**, this was found to be impractical for many applications **[I-D.ietf-httpbis-p1-messaging]**. For the same considerations, this specification does not mandate a particular maximum number of outstanding interactions, but instead encourages clients to be conservative when initiating interactions.)

The rationale for this design is that it is very easy to implement for a constrained device: a constrained device will already have a hard limit on the number of slots available for initiating transactions. However, in the text this SHOULD needs to be changed into a MUST.

In the following, we refer to the initiator parameter that limits the number of outstanding interactions as NSTART.

Clients SHOULD also heed this **[RFC5405]** guideline:

an application SHOULD perform congestion control over all UDP traffic it sends to a destination, independently from how it generates this traffic. For example, an application that forks multiple worker processes or otherwise uses multiple sockets to generate UDP datagrams SHOULD perform congestion control over the aggregate traffic.

Note that **[RFC5405]** is not explicit here with respect to what it considers to be a "destination"; it also uses the term "destination host" when it appears to provide specific discussion about all protocol entities at an IP address. **[RFC5405]** duly notes the failure of the congestion manager approach **[RFC3124]**, but appears to wish it back into existence. For the purposes of CoAP, probably "destination" here should be used as destination endpoint (i.e., including the UDP port number). Still, an implementation that e.g. uses a new source port per request (which is a valid strategy) needs to heed this SHOULD.

The count of outstanding interactions also needs to decay at some rate where there is a chance that a request would never elicit a response (e.g., due to a crashed server) but there is no timeout governing this exchange; a decay rate below that at which TCP sends to a very lossy channel (e.g., 7 B/s) should be safe.

There are also some special congestion control considerations with responses to multicast requests, see **[I-D.ietf-core-coap]** section 4.5; servers are expected to provide estimates for group size and a target rate as well as a response size. Where those estimates are hard to come up with, a default response dithering window of 10 seconds should be added to **[I-D.ietf-core-coap]**, as well an admonition for a client not to use

multicast requests when such a default window would be way off. Finally, a server that receives another multicast request within the dithering window for a request that it already is answering SHOULD move the dithering window for its next response to after the first dithering window.

Finally, the text in **[I-D.ietf-core-coap]** needs to be reviewed whether it always clearly separates the discussion for avoiding network congestion from any mechanisms for avoiding server overloading.

**[I-D.ietf-core-observe]** adds one additional behavior: servers that send NON messages as notifications for state changes, outside of exchanges that would be governed by NSTART. This needs to be supported with some discussion of congestion control. Generally, servers SHOULD NOT send more than one NON message every 3 seconds **[RFC5405]** section 3.1.2), and SHOULD NOT send NON messages while waiting for CON messages to be acknowledged. There already was a decision to add a requirement to send a CON message at least every 24 hours; probably the number of 3 seconds should be increased for servers that check the client that rarely (e.g., to the rate at which TCP sends into a very lossy channel, e.g., 7 B/s).

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## 4. How do other protocols do it

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While CoAP congestion control could be designed from first principles, it is maybe more realistic to have a look at how other protocols address its respective version of the problem.

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### 4.1. DNS

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The DNS protocol, which in many characteristics is quite close to CoAP, does not have any explicit mechanisms for congestion control at all. Many documents consider DNS to be “sporadic messages”, not worth of congestion control.

**[RFC4336]** says:

(The short flows generated by request-response applications, such as DNS and SNMP, don't cause congestion in practice, and any congestion control mechanism would take effect between flows, not within a single end- to-end transfer of information.)

(This simple packet-for-packet request-response nature is now changing a bit with DNS being used for voluminous keying information and growing TXT records.)

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### 4.2. SIP

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SIP uses a 0.5 s initial timeout (T1 “RTT Estimate”), and uses binary exponential increase after that. That is similar to CoAP, but starts from a smaller initial estimate. CoAP is more conservative (initial RESPONSE\_TIMEOUT is 2 s to 3 s) as we expect latencies in constrained networks to be higher than in the networks used for telephony.

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### 4.3. TCP

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A well-known problem with relying on TCP's built-in congestion control is that, even with all congestion-control mechanisms in place, simply multiplying the number of instances

may lead to eventual congestion.

TCP has increased its initial congestion window (IW) to about 3 packets [RFC3390] and is now moving to an IW of 10 packets (IW10) [I-D.ietf-tcpm-initcwnd]. A related change is also planned in that document that will avoid resetting this initial window when the SYN or SYN/ACK is lost. This means that it is considered appropriate to send about 15 kB of data on a single connection without any congestion control feedback whatsoever, except that some SYN+SYN/ACK exchange made it through. While [I-D.ietf-tcpm-initcwnd] is not yet approved, it is a WG document and there is some feeling of its inevitability.

The number 10 clearly provides some additional context for the selection of appropriate values of NSTART.

Conclusion:

For now, it is probably appropriate to RECOMMEND keeping NSTART at or below the value 10.

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## 4.4. HTTP

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HTTP is running on top of TCP, so is TCP-friendly by definition. However, as HTTP 1.0 was using one TCP connection per request, and it became clear that browser usage would entail fetching many objects in parallel, congestion was still observed, and implementations started to limit the number of simultaneously started connections. Even when persistent connections were added, and later codified in HTTP 1.1, this remained a concern. Under 8.1.4 "Practical considerations", [RFC2616] defines a limit on the number of simultaneous connections from one client to one server.

Clients that use persistent connections SHOULD limit the number of simultaneous connections that they maintain to a given server. A single-user client SHOULD NOT maintain more than 2 connections with any server or proxy. A proxy SHOULD use up to 2\*N connections to another server or proxy, where N is the number of simultaneously active users. These guidelines are intended to improve HTTP response times and avoid congestion.

Intended as a guideline, this has been implemented to the letter in browser clients for a decade. However, using this as a hard limit is simply not appropriate for all environments. This led server implementers to widely deploy workarounds, such as splitting up a website between multiple servers ("domain sharding") in order to increase the connection concurrency.

From this historical evidence we can learn that well-meaning limitations can cause a lot of pain when implemented slavishly. The httpbis effort has learned this lesson and removed the suggestion for a hard limit (see [HTTPBIS131], [HTTPBISc715]). Note that it now says:

Clients (including proxies) SHOULD limit the number of simultaneous connections that they maintain to a given server (including proxies).

Previous revisions of HTTP gave a specific number of connections as a ceiling, but this was found to be impractical for many applications. As a result, this specification does not mandate a particular maximum number of connections, but instead encourages clients to be conservative when opening multiple connections.

In particular, while using multiple connections avoids the "head-of-line blocking" problem (whereby a request that takes significant server-side processing and/or has a large payload can block subsequent requests on the same connection), each connection used consumes server resources



(sometimes significantly), and furthermore using multiple connections can cause undesirable side effects in congested networks.

Note that servers might reject traffic that they deem abusive, including an excessive number of connections from a client.

Conclusion:

There is no doubt that CoAP should follow this hard-learned expertise.

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## 5. Advanced CoAP Congestion Control

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### 5.1. RTT Measurement

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For an initiator that plans to make multiple requests to one destination end-point, it may be worthwhile to make RTT measurements in order to obtain a better RTT estimation than that implied by the default initial timeout of 2 to 3 s. The usual algorithms for RTT estimation can be used **[RFC6298]**, with appropriately extended default/base values. Note that such a mechanism **MUST**, during idle periods, decay RTT estimates that are shorter than the basic RTT estimate back to the basic RTT estimate.

One important consideration not relevant for TCP is the fact that a CoAP round-trip may include application processing time, which may be hard to predict. A client that has arrived at a RTT estimate much shorter than the 2 to 3 s used as a default **SHOULD** therefore not expend all of its retransmissions in the shorter estimated timescale.

It may also be worthwhile to do RTT estimates not just based on information measured from a single destinations endpoint, but also based on hosts (IP addresses) and/or prefixes (e.g., maintain an RTT estimate for a whole /64). The exact way this can be used to reduce the amount of state in an initiator is for further study.

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### 5.2. Block Slow-Start

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The CoAP protocol is not optimized for making good use of available network capacity; a TCP connection will always overtake a series of CoAP requests.

However, the **[I-D.ietf-core-block]** protocol can be used to emulate TCP slow start. E.g., a client can do a request for block 0, and, if a response comes back without a loss, it can fire off the requests for block 1 and block 2 at the same time, etc., using each response in a similar way that TCP would clock its data segments based on ACKs. Similar approaches may work to increase channel utilization for any other REST usage that requires multiple requests.

Clearly, the slow start period **MUST** terminate on the first loss/retransmission. How exactly the congestion window is to be maintained after that is a subject for further study. See also **[I-D.mathis-tcpm-tcp-laminar]** for fresh approaches to maintaining the necessary variables. Another alternative would be an implementation that emulates **[RFC5348]**.

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## 6. IANA Considerations

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This document makes no requirements on IANA. (This section to be removed by RFC editor.)



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## 7. Security Considerations

(TBD.)

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## 8. Acknowledgements

The first document to examine CoAP congestion control issues in more detail was [\[I-D.eggert-core-congestion-control\]](#), to which this draft owes a lot.

Michael Scharf did a review of CoAP congestion control issues that asked a lot of the questions that this draft attempts to answer.

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## Authors' Addresses

Carsten Bormann (editor)  
Universitaet Bremen TZI  
Postfach 330440  
Bremen D-28359  
Germany  
**Phone:** +49-421-218-63921  
**Email:** [cabo@tzi.org](mailto:cabo@tzi.org)

Klaus Hartke  
Universität Bremen TZI  
Postfach 330440  
Bremen D-28359  
Germany  
**Phone:** +49-421-218-63905  
**Email:** [hartke@tzi.org](mailto:hartke@tzi.org)