

Enabling Edge Computing over LoRaWAN: A Device-Gateway Coordination Protocol

STEPHEN SPENCER, University of Washington, USA

STEFANO MILANI*, Sapienza University of Rome, Italy

FRANCESCA CUOMO*, University of Rome Sapienza, Italy

IOANNIS CHATZIGIANNAKIS, Sapienza University of Rome, Italy



Fig. 1. Panoramic Photography of City Near Body of Water. Photo by Ralph Chang from Pixabay.

Please note that TAPS will generate the title and author information for the generated PDF and HTML versions of this document from the information provided by the contact author on the completed rights form, instead of the title and author information provided by the author in the source materials. You still need to include that information if (a) you are preparing your source material in LaTeX and (b) you wish to use the “authornote” and “authornotemark” commands, as shown in this example.

*Equal contribution.

Authors' Contact Information: Stephen Spencer, Paul G. Allen School for Computer Science and Engineering, University of Washington, Seattle, WA, USA, spencer9@uw.edu; Stefano Milani, Department of Computer, Control and Management Engineering (DIAG), Sapienza University of Rome, Rome, Italy, milani@diag.uniroma1.it; Francesca Cuomo, Department of Information Engineering, Electronics and Telecommunications, University of Rome Sapienza, Rome, Italy, francesca.cuomo@uniroma1.it; Ioannis Chatzigiannakis, Department of Computer, Control and Management Engineering, Sapienza University of Rome, Rome, Italy, ichatz@diag.uniroma1.it.

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than the author(s) must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from permissions@acm.org.

© 2024 Copyright held by the owner/author(s). Publication rights licensed to ACM.
ACM 1557-7368/2024/12-ART99
<https://doi.org/10.1145/3702307>

Duis cursus placerat leo ac vehicula. Donec id dolor vel nunc maximus consectetur. Morbi pharetra, odio quis mattis gravida, orci dolor fermentum arcu, id tempus ante ante ut justo. Pellentesque fringilla orci a quam lacinia, non mollis orci blandit. Aliquam erat volutpat. Duis sit amet magna commodo, faucibus risus sed, dictum tortor. Cras porttitor facilisis libero non rutrum. Nullam dignissim velit a quam finibus, sed consectetur arcu mattis.

CCS Concepts: • **Computing methodologies** → **Animation**.

Additional Key Words and Phrases: this, that, other

ACM Reference Format:

Stephen Spencer, Stefano Milani, Francesca Cuomo, and Ioannis Chatzigiannakis. 2024. Enabling Edge Computing over LoRaWAN: A Device-Gateway Coordination Protocol. *ACM Trans. Graph.* 43, 6, Article 99 (December 2024), 6 pages. <https://doi.org/10.1145/3702307>

1 Introduction

The outcome in Brussels today signals a tough road ahead to secure commitments on climate action not only from European nations, but from other big polluters as well. New president of the European Commission Ursula von der Leyen just released the EU's Green Deal on December 11 [Hagerup et al. 1993], a sweeping package of policy proposals aimed at drastically reducing emissions by 2050. Her announcement followed the November declaration by the European Parliament of a "climate emergency" - a phrase that activists

with Greenpeace hung from the building where the Council met in Brussels.

Following biochar’s recognition in the IPCC 2018 report, earlier this year Redmile-Gordon launched the society’s first trials to see how the material could improve plant growth. He estimates planting 10-20kg of biochar in your garden could offset the carbon from a five-mile return commute in a car for a month. Biochar is a form of charcoal produced when organic matter – for example wood, leaves or dead plants – is heated at high temperatures with little or no oxygen in a process called pyrolysis. The normal burning or decomposition of these materials would release large amounts of methane and carbon dioxide into the atmosphere. Instead, creating biochar traps this carbon in solid form for centuries; it becomes a carbon sink that can be buried underground. [Bowman et al. 1993; Braams 1991; Herlihy 1993]

GOES-17 went up to work with GOES-16, another NOAA weather satellite that was launched in 2016. The two probes, which are part of the so-called GOES-R series, are able to scan most of the Western Hemisphere from the coast of Africa all the way to New Zealand. Their observations from 22,300 miles (almost 36,000 kilometers) above Earth are key to monitor hurricanes, droughts, wildfires, lighting, and fog. The two spacecraft also provide us with stunning views of our planet.

2 Related Work

These companies are partners with NASA through the agency’s Commercial Lunar Payload Services (CLPS) initiative. CLPS is the first phase of NASA’s Artemis program, the agency’s initiative to send the first woman and the next man to the Moon. But CLPS is focused on robotic vehicles and science, rather than human space-flight. The goal is to send instruments and science experiments to the surface of the Moon using commercial landers that are developed and operated by private companies.

2.1 Sample Subsection 1

During a test yesterday, SpaceX fired up the engines on one of its Falcon 9 rockets, a vehicle that will perform a crucial test flight for NASA in the months ahead. It’s the rocket that will carry SpaceX’s new Crew Dragon capsule to space for the first time to prove that the spacecraft is ready to ferry NASA astronauts.

The statement was made after the British host of the meeting, Boris Johnson, and United Nations secretary-general, Antonio Guterres, urged all countries to lift their targets to include net zero emissions by 2050, noting 121 nations had already done so. Labor’s Pat Conroy asked Angus Taylor, the energy and emissions reduction minister, in February whether Australia was due under the Paris agreement to submit a new or updated commitment this year and, if not, when it was expected.

2.2 Sample Subsection 2

The European Space Agency calls the crater a “cold trap,” where air moving over the frigid ice is cooled, creating a kind of chilly barrier between the ice within the crater and warmer parts of the atmosphere – even in the summer. This isn’t the first time that Korolev crater has had a moment in the spotlight. NASA snapped

it making waves in the Martian clouds in 2003, and in April of this year, one of the first images the ESA’s Trace Gas Orbiter captured was a gorgeous shot of the crater’s rim.

2.2.1 Sample Subsubsection 1. The flight represents a breakthrough in “ionic wind” technology, which uses a powerful electric field to generate charged nitrogen ions, which are then expelled from the back of the aircraft, generating thrust. Steven Barrett, an aeronautics professor at MIT and the lead author of the study published in the journal *Nature*, said the inspiration for the project came straight from the science fiction of his childhood. “I was a big fan of *Star Trek*, and at that point I thought that the future looked like it should be planes that fly silently, with no moving parts – and maybe have a blue glow.”

Following biochar’s recognition in the IPCC 2018 report, earlier this year Redmile-Gordon launched the society’s first trials to see how the material could improve plant growth. He estimates planting 10-20kg of biochar in your garden could offset the carbon from a five-mile return commute in a car for a month. Biochar is a form of charcoal produced when organic matter – for example wood, leaves or dead plants – is heated at high temperatures with little or no oxygen in a process called pyrolysis. The normal burning or decomposition of these materials would release large amounts of methane and carbon dioxide into the atmosphere. Instead, creating biochar traps this carbon in solid form for centuries; it becomes a carbon sink that can be buried underground.

2.2.2 Sample Subsubsection 2. During a test yesterday, SpaceX fired up the engines on one of its Falcon 9 rockets, a vehicle that will perform a crucial test flight for NASA in the months ahead. It’s the rocket that will carry SpaceX’s new Crew Dragon capsule to space for the first time to prove that the spacecraft is ready to ferry NASA astronauts.

Table 1. American League West Standings, 2024

Team	W	L	Pct	GB	Home	Away	L10
Astros	88	73	.547	-	46-35	42-38	6-4
Mariners	85	77	.525	3.5	49-32	36-45	8-2
Rangers	78	84	.481	10.5	44-37	34-47	5-5
Athletics	69	93	.426	19.5	38-43	31-50	3-7
Angels	63	99	.389	25.5	32-49	31-50	1-9

Following biochar’s recognition in the IPCC 2018 report, earlier this year Redmile-Gordon launched the society’s first trials to see how the material could improve plant growth. He estimates planting 10-20kg of biochar in your garden could offset the carbon from a five-mile return commute in a car for a month. Biochar is a form of charcoal produced when organic matter – for example wood, leaves or dead plants – is heated at high temperatures with little or no oxygen in a process called pyrolysis. The normal burning or decomposition of these materials would release large amounts of methane and carbon dioxide into the atmosphere. Instead, creating biochar traps this carbon in solid form for centuries; it becomes a carbon sink that can be buried underground.



Fig. 2. Figs. Image by Stefan Schwehofer from Pixabay.

3 Another Section

GOES-17 went up to work with GOES-16, another NOAA weather satellite that was launched in 2016. The two probes, which are part of the so-called GOES-R series, are able to scan most of the Western Hemisphere from the coast of Africa all the way to New Zealand. Their observations from 22,300 miles (almost 36,000 kilometers) above Earth are key to monitor hurricanes, droughts, wildfires, lighting, and fog. The two spacecraft also provide us with stunning views of our planet.

3.1 Sample Subsection

Following biochar's recognition in the IPCC 2018 report, earlier this year Redmile-Gordon launched the society's first trials to see how the material could improve plant growth. He estimates planting 10-20kg of biochar in your garden could offset the carbon from a five-mile return commute in a car for a month. Biochar is a form of charcoal produced when organic matter – for example wood, leaves or dead plants – is heated at high temperatures with little or no oxygen in a process called pyrolysis. The normal burning or decomposition of these materials would release large amounts of methane and carbon dioxide into the atmosphere. Instead, creating biochar traps this carbon in solid form for centuries; it becomes a carbon sink that can be buried underground.

3.1.1 Sample Subsubsection. GOES-17 went up to work with GOES-16, another NOAA weather satellite that was launched in 2016. The two probes, which are part of the so-called GOES-R series, are able to scan most of the Western Hemisphere from the coast of Africa all the way to New Zealand. Their observations from 22,300 miles (almost 36,000 kilometers) above Earth are key to monitor hurricanes, droughts, wildfires, lighting, and fog. The two spacecraft also provide us with stunning views of our planet.

The Taylor series expansion for the function e^x is given by

$$e^x = 1 + x + \frac{x^2}{2} + \frac{x^3}{6} + \dots = \sum_{n=0}^{\infty} \frac{x^n}{n!} \quad (1)$$

Sample Paragraph. GOES-17 went up to work with GOES-16, another NOAA weather satellite that was launched in 2016. The two probes, which are part of the so-called GOES-R series, are able to scan most of the Western Hemisphere from the coast of Africa all the way to New Zealand. Their observations from 22,300 miles (almost 36,000 kilometers) above Earth are key to monitor hurricanes, droughts, wildfires, lighting, and fog. The two spacecraft also provide us with stunning views of our planet.

GOES-17 went up to work with GOES-16, another NOAA weather satellite that was launched in 2016. The two probes, which are part of the so-called GOES-R series, are able to scan most of the Western Hemisphere from the coast of Africa all the way to New Zealand. Their observations from 22,300 miles (almost 36,000 kilometers) above Earth are key to monitor hurricanes, droughts, wildfires, lighting, and fog. The two spacecraft also provide us with stunning views of our planet.

The outcome in Brussels today signals a tough road ahead to secure commitments on climate action not only from European nations, but from other big polluters as well. New president of the European Commission Ursula von der Leyen just released the EU's Green Deal on December 11, a sweeping package of policy proposals aimed at drastically reducing emissions by 2050. Her announcement followed the November declaration by the European Parliament of a "climate emergency" – a phrase that activists with Greenpeace hung from the building where the Council met in Brussels.

The flight represents a breakthrough in "ionic wind" technology, which uses a powerful electric field to generate charged nitrogen ions, which are then expelled from the back of the aircraft, generating thrust. Steven Barrett, an aeronautics professor at MIT and the lead author of the study published in the journal Nature, said the inspiration for the project came straight from the science fiction of his childhood. "I was a big fan of Star Trek, and at that point I thought that the future looked like it should be planes that fly silently, with no moving parts – and maybe have a blue glow."

Following biochar's recognition in the IPCC 2018 report, earlier this year Redmile-Gordon launched the society's first trials to see how the material could improve plant growth. He estimates planting 10-20kg of biochar in your garden could offset the carbon from a five-mile return commute in a car for a month. Biochar is a form of charcoal produced when organic matter – for example wood, leaves or dead plants – is heated at high temperatures with little or no oxygen in a process called pyrolysis. The normal burning or decomposition of these materials would release large amounts of methane and carbon dioxide into the atmosphere. Instead, creating biochar traps this carbon in solid form for centuries; it becomes a carbon sink that can be buried underground.

4 Yet Another Section

The flight represents a breakthrough in "ionic wind" technology, which uses a powerful electric field to generate charged nitrogen ions, which are then expelled from the back of the aircraft, generating thrust. Steven Barrett, an aeronautics professor at MIT and the lead author of the study published in the journal Nature, said the inspiration for the project came straight from the science fiction of his childhood. "I was a big fan of Star Trek, and at that point I thought that the future looked like it should be planes that fly silently, with no moving parts – and maybe have a blue glow."

- (1) This is the first item in the list.
- (2) This is the second item in the list.

The statement was made after the British host of the meeting, Boris Johnson, and United Nations secretary-general, Antonio Guterres, urged all countries to lift their targets to include net zero emissions by 2050, noting 121 nations had already done so. Labor's Pat

Conroy asked Angus Taylor, the energy and emissions reduction minister, in February whether Australia was due under the Paris agreement to submit a new or updated commitment this year and, if not, when it was expected.

- This is the first item in the list.
- This is the second item in the list.
- This is the last item in the list.

GOES-17 went up to work with GOES-16, another NOAA weather satellite that was launched in 2016. The two probes, which are part of the so-called GOES-R series, are able to scan most of the Western Hemisphere from the coast of Africa all the way to New Zealand. Their observations from 22,300 miles (almost 36,000 kilometers) above Earth are key to monitor hurricanes, droughts, wildfires, lighting, and fog. The two spacecraft also provide us with stunning views of our planet.

The outcome in Brussels today signals a tough road ahead to secure commitments on climate action not only from European nations, but from other big polluters as well. New president of the European Commission Ursula von der Leyen just released the EU's Green Deal on December 11, a sweeping package of policy proposals aimed at drastically reducing emissions by 2050. Her announcement followed the November declaration by the European Parliament of a "climate emergency" - a phrase that activists with Greenpeace hung from the building where the Council met in Brussels.



Fig. 3. Street With People Walking during Night. Photo by Abby Chung from Pexels.

Following biochar's recognition in the IPCC 2018 report, earlier this year Redmile-Gordon launched the society's first trials to see how the material could improve plant growth. He estimates planting 10-20kg of biochar in your garden could offset the carbon from a five-mile return commute in a car for a month. Biochar is a form of charcoal produced when organic matter - for example wood, leaves or dead plants - is heated at high temperatures with little or no oxygen in a process called pyrolysis. The normal burning or decomposition of these materials would release large amounts of methane and carbon dioxide into the atmosphere. Instead, creating biochar traps this carbon in solid form for centuries; it becomes a carbon sink that can be buried underground.



Fig. 4. Gray Concrete Pathway Between Red-and-black Pillars. Photo by Vincent M. A. Janssen from Pexels.

During a test yesterday, SpaceX fired up the engines on one of its Falcon 9 rockets, a vehicle that will perform a crucial test flight for NASA in the months ahead. It's the rocket that will carry SpaceX's new Crew Dragon capsule to space for the first time to prove that the spacecraft is ready to ferry NASA astronauts.

The outcome in Brussels today signals a tough road ahead to secure commitments on climate action not only from European nations, but from other big polluters as well. New president of the European Commission Ursula von der Leyen just released the EU's Green Deal on December 11, a sweeping package of policy proposals aimed at drastically reducing emissions by 2050. Her announcement followed the November declaration by the European Parliament of a "climate emergency" - a phrase that activists with Greenpeace hung from the building where the Council met in Brussels.

Following biochar's recognition in the IPCC 2018 report, earlier this year Redmile-Gordon launched the society's first trials to see how the material could improve plant growth. He estimates planting 10-20kg of biochar in your garden could offset the carbon from a five-mile return commute in a car for a month. Biochar is a form of charcoal produced when organic matter - for example wood, leaves or dead plants - is heated at high temperatures with little or no oxygen in a process called pyrolysis. The normal burning or decomposition of these materials would release large amounts of methane and carbon dioxide into the atmosphere. Instead, creating biochar traps this carbon in solid form for centuries; it becomes a carbon sink that can be buried underground.

GOES-17 went up to work with GOES-16, another NOAA weather satellite that was launched in 2016. The two probes, which are part of the so-called GOES-R series, are able to scan most of the Western Hemisphere from the coast of Africa all the way to New Zealand. Their observations from 22,300 miles (almost 36,000 kilometers) above Earth are key to monitor hurricanes, droughts, wildfires, lighting, and fog. The two spacecraft also provide us with stunning views of our planet.

5 One More Section, For Good Measure

GOES-17 went up to work with GOES-16, another NOAA weather satellite that was launched in 2016. The two probes, which are part

of the so-called GOES-R series, are able to scan most of the Western Hemisphere from the coast of Africa all the way to New Zealand. Their observations from 22,300 miles (almost 36,000 kilometers) above Earth are key to monitor hurricanes, droughts, wildfires, lighting, and fog. The two spacecraft also provide us with stunning views of our planet.

GOES-17 went up to work with GOES-16, another NOAA weather satellite that was launched in 2016. The two probes, which are part of the so-called GOES-R series, are able to scan most of the Western Hemisphere from the coast of Africa all the way to New Zealand. Their observations from 22,300 miles (almost 36,000 kilometers) above Earth are key to monitor hurricanes, droughts, wildfires, lighting, and fog. The two spacecraft also provide us with stunning views of our planet.

The outcome in Brussels today signals a tough road ahead to secure commitments on climate action not only from European nations, but from other big polluters as well. New president of the European Commission Ursula von der Leyen just released the EU's Green Deal on December 11, a sweeping package of policy proposals aimed at drastically reducing emissions by 2050. Her announcement followed the November declaration by the European Parliament of a "climate emergency"- a phrase that activists with Greenpeace hung from the building where the Council met in Brussels.

GOES-17 went up to work with GOES-16, another NOAA weather satellite that was launched in 2016. The two probes, which are part of the so-called GOES-R series, are able to scan most of the Western Hemisphere from the coast of Africa all the way to New Zealand. Their observations from 22,300 miles (almost 36,000 kilometers) above Earth are key to monitor hurricanes, droughts, wildfires, lighting, and fog. The two spacecraft also provide us with stunning views of our planet.

The outcome in Brussels today signals a tough road ahead to secure commitments on climate action not only from European nations, but from other big polluters as well. New president of the European Commission Ursula von der Leyen just released the EU's Green Deal on December 11, a sweeping package of policy proposals aimed at drastically reducing emissions by 2050. Her announcement followed the November declaration by the European Parliament of a "climate emergency"- a phrase that activists with Greenpeace hung from the building where the Council met in Brussels.

GOES-17 went up to work with GOES-16, another NOAA weather satellite that was launched in 2016. The two probes, which are part of the so-called GOES-R series, are able to scan most of the Western Hemisphere from the coast of Africa all the way to New Zealand. Their observations from 22,300 miles (almost 36,000 kilometers) above Earth are key to monitor hurricanes, droughts, wildfires, lighting, and fog. The two spacecraft also provide us with stunning views of our planet.

GOES-17 went up to work with GOES-16, another NOAA weather satellite that was launched in 2016. The two probes, which are part of the so-called GOES-R series, are able to scan most of the Western Hemisphere from the coast of Africa all the way to New Zealand. Their observations from 22,300 miles (almost 36,000 kilometers) above Earth are key to monitor hurricanes, droughts, wildfires, lighting, and fog. The two spacecraft also provide us with stunning views of our planet.

The outcome in Brussels today signals a tough road ahead to secure commitments on climate action not only from European nations, but from other big polluters as well. New president of the European Commission Ursula von der Leyen just released the EU's Green Deal on December 11, a sweeping package of policy proposals aimed at drastically reducing emissions by 2050. Her announcement followed the November declaration by the European Parliament of a "climate emergency"- a phrase that activists with Greenpeace hung from the building where the Council met in Brussels.

The outcome in Brussels today signals a tough road ahead to secure commitments on climate action not only from European nations, but from other big polluters as well. New president of the European Commission Ursula von der Leyen just released the EU's Green Deal on December 11, a sweeping package of policy proposals aimed at drastically reducing emissions by 2050. Her announcement followed the November declaration by the European Parliament of a "climate emergency"- a phrase that activists with Greenpeace hung from the building where the Council met in Brussels.

6 Conclusion and Future Work

Following biochar's recognition in the IPCC 2018 report, earlier this year Redmile-Gordon launched the society's first trials to see how the material could improve plant growth. He estimates planting 10-20kg of biochar in your garden could offset the carbon from a five-mile return commute in a car for a month. Biochar is a form of charcoal produced when organic matter – for example wood, leaves or dead plants – is heated at high temperatures with little or no oxygen in a process called pyrolysis. The normal burning or decomposition of these materials would release large amounts of methane and carbon dioxide into the atmosphere. Instead, creating biochar traps this carbon in solid form for centuries; it becomes a carbon sink that can be buried underground.

During a test yesterday, SpaceX fired up the engines on one of its Falcon 9 rockets, a vehicle that will perform a crucial test flight for NASA in the months ahead. It's the rocket that will carry SpaceX's new Crew Dragon capsule to space for the first time to prove that the spacecraft is ready to ferry NASA astronauts.

GOES-17 went up to work with GOES-16, another NOAA weather satellite that was launched in 2016. The two probes, which are part of the so-called GOES-R series, are able to scan most of the Western Hemisphere from the coast of Africa all the way to New Zealand. Their observations from 22,300 miles (almost 36,000 kilometers) above Earth are key to monitor hurricanes, droughts, wildfires, lighting, and fog. The two spacecraft also provide us with stunning views of our planet.

Acknowledgments

Thanks to Corporate Lorem - <https://corporatelorem.kovah.de/> and "lipsum.com" - <https://www.lipsum.com/> for the "Lorem Ipsum" text.

References

- Mic Bowman, Saumya K. Debray, and Larry L. Peterson. 1993. Reasoning About Naming Systems. *ACM Trans. Program. Lang. Syst.* 15, 5 (November 1993), 795–825. <https://doi.org/10.1145/161468.161471>
- Johannes Braams. 1991. Babel, a Multilingual Style-Option System for Use with LaTeX's Standard Document Styles. *TUGboat* 12, 2 (June 1991), 291–301.

Torben Hagerup, Kurt Mehlhorn, and J. Ian Munro. 1993. Maintaining Discrete Probability Distributions Optimally. In *Proceedings of the 20th International Colloquium on Automata, Languages and Programming (Lecture Notes in Computer Science, Vol. 700)*. Springer-Verlag, Berlin, 253–264.

Maurice Herlihy. 1993. A Methodology for Implementing Highly Concurrent Data Objects. *ACM Trans. Program. Lang. Syst.* 15, 5 (November 1993), 745–770. <https://doi.org/10.1145/161468.161469>