FogROS 2: An Adaptive and Extensible Platform for Cloud and Fog Robotics Using ROS 2

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Abstract—Mobility, power, and price points often dictate that robots do not have sufficient computing power on board to run modern robot algorithms at desired rates. Cloud computing providers such as AWS, GCP, and Azure offer immense computing power on demand, but tapping into that power from a robot is non-trivial. In this paper, we present FogROS 2, an easy-to-use, open-source platform to facilitate cloud and fog robotics that is compatible with the emerging Robot Operating System 2 (ROS 2) standard. FogROS 2 provides a cloud computer, deploys and launches ROS 2 nodes to the cloud computer, sets up secure networking between the robot and cloud, and starts the application running. FogROS 2 is completely redesigned and distinct from its predecessor to support ROS 2 applications, transparent video compression and communication, improved performance and security, support for multiple cloud-computing providers, and remote monitoring and visualization. We demonstrate in example applications that the performance gained by using cloud computers can overcome the network latency to significantly speed up robot performance. In examples, FogROS 2 reduces SLAM latency by 50\%, reduces grasp planning time from 14s to 1.2s, and speeds up motion planning 28x. When compared to alternatives, FogROS 2 reduces network utilization by up to 3.8x. FogROS 2, source, examples, and documentation is available at \url{https://github.com/BerkeleyAutomation/FogROS2}

I. INTRODUCTION

The onboard computing power of robots is often unable to keep up with advances in robot algorithms and new computing hardware. Cloud computing offers on-demand access to immense computing resources and new and power-hungry computing platforms, such as GPUs, TPUs, and FPGAs. Prior work \cite{1} showed that using the cloud for intensive computing in robotics can be practical and cost-effective. However, gaining access to evolving cloud computing resources requires expertise with many new and emerging software packages, and experience handling data security and privacy. In prior work, we introduced FogROS \cite{2}, an easy-to-use framework that extends the Robot Operating System (ROS) to enable quick access to the cloud. In this paper, we introduce FogROS 2, which ports FogROS to ROS 2 and substantially extends performance, capabilities, compatibility, and extensibility.

Cloud computing services, such as Amazon Web Services (AWS), Google Cloud Platform (GCP), and Microsoft Azure, offer on-demand pay-per-use networked access to remote computing hardware and services. Using these services typically requires a one-time setup to create an account and associate a payment method. After setup, users can turn on and off cloud computers to their specification (e.g., number of CPU cores, GPUs, FPGAs, etc.) through a web browser or programmatic interface. To use a cloud computer in a robotics application, the robot software must be transferred...
to run on the cloud, and the robot must also have a way to communicate with the software—FogROS 2 automates this.

ROS 2 [3], a rapidly growing replacement for ROS [4], is a standard for developing robot applications. FogROS 2 enables moving computationally intensive parts (or nodes) of a ROS 2 computational graph to the cloud and secures communication channel for messages, all with a few small changes to the launch script and without changing a line of the robot code. On launch, FogROS 2 processes a user-provided script to determine which nodes need to be deployed, provisions cloud computers, deploys the nodes to those computers, secures and sets up network routing, and starts the code running. The only observable difference between robot nodes and cloud-deployed nodes is the latency of computation. FogROS 2 is ideally suited for robot applications where the performance gained by using a cloud computer overcomes the network latency to significantly increase robot capabilities and responsiveness.

Using 3 example applications, visual SLAM, grasp planning, and motion planning, we evaluate FogROS 2’s ability to reduce computation times. FogROS 2 can reduce compute times by 2x to 28x, and its streaming video compression enables more responsive cloud-based processing of streaming images, reducing latency by 50% in applications such as visual SLAM where real-time pose estimation is critical.

FogROS 2 makes several improvements over FogROS:

- FogROS 2 extends the ROS 2 launch system introducing additional syntax in launch files that allow roboticists to specify at launch time which components of their architecture will be deployed to the cloud, and which ones on the robot.
- FogROS 2 adds support for streaming video compression between robot and cloud nodes—significantly improving the performance of image processing in the cloud, and potentially enabling new applications.
- The architecture of FogROS 2 is extensible, making it easy to plug in support for additional cloud computing providers, Data Distribution Service (DDS) providers (Sec. III), and message compression.
- FogROS 2 integrates fully with ROS 2 and provides ROS 2 command-line interfaces to query and control cloud-robotics deployments.
- FogROS 2 interfaces with the new Foxglove web-based robot visualization software [5] to allow remote monitoring of FogROS 2 applications.

A. Design Principles

FogROS 2 aims to meet the following design principies:

a) All the features of FogROS: FogROS design principles included: transparency to software, flexible computing resources, minimal configuration requirements, pre-deployed nodes, and security and isolation. We, however, drop the FogROS approach of configurable network transport (Proxy or Virtual Private Networking (VPN)), as the Proxy option was an underutilized feature, and instead use VPN exclusively.

b) Full ROS 2 Integration: FogROS 2 will be a full-fledged member of the ROS 2 ecosystem, and integrate with the ros2 command-line interface and a revamped launch system.

c) Faster Image Processing: One of the main bottlenecks of robot-cloud communication is sending video and images to the cloud. FogROS 2 should leverage streaming compression to transmit images to the cloud for rapid processing.

d) Remotely Monitorable: As monitoring and intervention is an important part of many remote and cloud-based robotics applications, FogROS 2 should provide simple mechanisms for remotely monitoring and visualizing cloud-robotics deployments.

e) Extensible Architecture: Cloud-computing is ever evolving. FogROS 2 should provide mechanisms for integrating with future cloud and networking providers.

II. RELATED WORK

Cloud-robotics platforms facilitate offloading computation and data to the cloud. A notable example is RoboEarth [6], which shared information between robot and cloud. The main use case was to use the cloud to share databases between robots, but it did not leverage the cloud for offloading computing. Rapyuta [7] emerged from RobotEarth to become a platform for centralized management of robot fleets. In Rapyuta, robot nodes or Docker images are built on the cloud and pushed to the registered robots. A similar approach is taken by AWS Greengrass [8]. Using proprietary interfaces, Rapyuta and Greengrass allow building and deploying an entire pipeline for robotics applications [9], [10], [11], [12]. In contrast, FogROS 2 reverses this direction. Instead of pushing an application from the cloud to a robot, FogROS 2 pushes robot nodes to the cloud using an interface familiar to ROS 2 developers, allowing developers and researchers to access cloud resources without learning or conforming to an additional framework.

As robots have limited onboard computing capabilities and the computing demands of robotics algorithms grow, the cloud has become an increasingly necessary source of computing power. Researchers have explored using the cloud for grasp planning (e.g., Kehoe et al. [13], Tian et al. [14], and Li et al. [15]), parallelized Monte-Carlo grasp perturbation sampling [16], [17], [18], motion planning services (e.g., Lam et al. [9]), and splitting motion plan computation between robot and cloud (e.g., Bekris et al. [19] and Ichnowski et al. [20]). Researchers also have explored using new cloud computing paradigms as they emerge, such as serverless computing [21], [22], in which algorithms run (and are charged) for short bursts of intensive computing; while others have explored using the cloud to gain access to hardware accelerators such as FPGAs [23]. Kehoe et al. [24] survey the landscape of cloud robotics, including capabilities, potential applications, and challenges. Others have explored some of these challenges, such as preserving privacy [25] and sharing models between robots [26]. In many of these examples, using the cloud requires a custom one-off implementation
or interfacing with a proprietary library. FogROS 2 aims to become a platform on which using the cloud for computing is simplified to standard ROS 2.

For a robot to gain access to cloud resources, it must provision a cloud computer and establish a network connection to it. As robots operate in the physical world, the connection to the cloud must be secured. However, setting this up is an involved process, in some cases requiring over 12 steps for configuration and 37 steps for verification [27]. Hajjaj et al. [27] explored using SSH tunneling for communication with ROS nodes running in the cloud. However, SSH tunnels do not support UDP which is needed when using ROS 2 Data Distribution Service (DDS) over UDP (while some DDS implementations support TCP, using TCP can introduce performance issues, and add unnecessary overhead for local communication). Crick et al. proposed rosbridge [28], Pereira et al. [29] proposed ROS Remote, and Xu et al. proposed MSA [30] as alternate ROS communication stacks with varying degrees of security and modifications required for their use in ROS applications. Wan et al. [31] and Saha et al. [32] propose unifying robot-cloud communication. Lim et al. proposed using VPNs [33], and FogROS 2 builds on this approach. FogROS 2 allows ROS 2 applications to easily use the cloud without code modification, and with secured communication.

III. BACKGROUND

ROS 2 [3], the successor to Robot Operating System (ROS), includes many substantial improvements. One of the core improvements in ROS 2 is its change from a proprietary pub/sub system to the industry standard middleware Distributed Data Service (DDS). DDS addresses concerns common in robotics, such as providing real-time, high-performance, interoperable, and reliable communication [34]. As DDS is a specification, there are several implementations, and ROS 2 is agnostic to DDS implementation.

In ROS 2, computational units are abstracted into nodes that communicate with each other via a publication/subscription (pub/sub) system. Nodes subscribe to named topics and receive messages (data) as other nodes publish them. In an example ROS 2 application (Fig. 1), a camera node publishes images, a Simultaneous Location And Mapping (SLAM) node processes the images and publishes a location and map, a Motion Planner node receive the map and then computes and publishes a location and map, a Simultaneous Location And Mapping (SLAM) node receives messages, and a path following node drives the wheels to reach a target.

When orchestrating a robot application, often multiple nodes must be launched simultaneously. The ROS 2 launch system facilitates this by providing the ability to specify all required nodes, topic mappings, and relations between nodes in a single python script file. Launching the robot application is then a matter of running the command:

```
ros2 launch <package> <script>.
```

Listing 1, without the circled FogROS 2 extensions, shows an example launch script that launches two nodes, a “grasp motion” and a “grasp planner.”

```python
def generate_launch_description():
    ld = FogROS2LaunchDescription()
    # configure cloud machine with a GPU (g4dn)
    machine1 = AWSCloudInstance(
        region="us-west-1",
        ec2_instance_type="g4dn.xlarge")
    # launch grasp motion node on robot
    grasp_planner_node = CloudNode(
        package="fogros2_examples",
        executable="grasp_planner",
        output="screen",
        machine=machine1)
    ld.add_action(grasp_planner_node)
    # launch grasp planner node in on the cloud
    grasp_motion_node = Node(
        package="fogros2_examples",
        executable="grasp_motion",
        output="screen")
    ld.add_action(grasp_motion_node)
    return ld
```

Listing 1: FogROS 2 Launch Script Example. This example launches two nodes. The FogROS 2 launch extensions are circled. The first extension defines a machine on which to launch nodes. The second tells FogROS 2 to launch the grasp planner node on that machine.

![Fig. 2: FogROS 2 Launch Sequence](image)

Fig. 2: FogROS 2 Launch Sequence FogROS 2 launches cloud nodes with the following sequence: (1) provision a VM, (2) install ROS and dependencies, (3) setup VPN, (4) copy ROS workspace to VM, (5) setup DDS, (6) launch cloud-based docker nodes, (7) launch cloud-based nodes, and (8) launch robot nodes. The gray nodes on the Robot are copied to the cloud computer and only launched in the cloud.

IV. APPROACH

To create an adaptive and extensible cloud-robotics platform, FogROS 2 extends the ROS 2 launch system, integrates into ROS 2 command line interfaces, implements a fast video streaming compression plugin, defines a modular cloud service provider abstraction and implements it for AWS and GCP, defines a modular DDS-provider abstraction and implements two popular providers, integrates a web-based robot visualization tool and deploys it to the cloud. Fig. 1(b) provides an overview of the modules implemented in FogROS 2.

A. ROS 2 Launch Integration

At the front end of FogROS 2 is the launch system—and extension of the ROS 2 system that specifies what nodes to launch. The FogROS2 extensions add the ability to define cloud computers or machines, and define on which machines nodes should run. Listing 1 shows an example in which a grasp planner needs a GPU to run efficiently. The script first defines a cloud machine with a GPU, then adds an attribute to the grasp planner node to tell the FogROS 2 launch process to run it on the cloud machine. In more extensive use cases,
multiple nodes can run on the same machine, and FogROS 2 can launch multiple machines. FogROS 2 also allows the script to specify docker instances to run in the cloud.

We implement the FogROS 2 launch sequence, shown in Fig. [2] that starts after processing the launch script. The steps FogROS 2 takes are: (1) connect to the cloud provider through its programmatic interface to create and start a new instance along with setting up security groups to isolate from other cloud computers, and generating secure communication key pairs; (2) install the ROS libraries and dependencies on the cloud machine needed for the robot application to run in the cloud; (3) set up virtual private networking (VPN) on robot and cloud machine to secure the ROS 2 DDS communication between them; (4) copy the workspace and all of its node software, from the robot to the cloud machine; (5) configure the DDS provider’s discovery mechanism to work across the VPN; (6) launch docker instances; (7) launch cloud-based nodes; and finally, (8) launch nodes on the robot.

Once the launch process is complete, the nodes running on the robot and on the cloud machine(s) securely communicate and interact with each other—and the only change needed was a few lines of the launch script.

1) Cloud Provider Modules: There are many cloud computing providers, each with a proprietary interface. To support the different providers, FogROS 2 has an extensible system where each provider has a named module (e.g., AWS, GCP) that communicates with the associated cloud provider. Each module implements methods to provision computing machines, start and stop machines, secure network communication, and push ROS nodes to the cloud machines. The launch script specifies the machine and provider-specific options, such as region and instance type. For example, the following snippet of a launch script specifies an AWS instance in the us-west-1 region:

```python
AWS(region="us-west-1",
  ec2_instance_type="t2.micro")
```

As provider interfaces differ significantly, we write a python class for each provider from scratch while adhering to a shared abstraction. For example, each provider class must implement methods to create and delete instances—in total we implement (and test) 19 methods for each supported provider. The initial release of FogROS 2 supports AWS and GCP, and we expect to add support for additional providers in the future.

2) DDS Provider Plugins: ROS 2 used Distributed Data Service (DDS) as a middleware communication protocol between nodes, but is agnostic to which DDS provider is used. As DDS is a specification, there are multiple implementations and it is left to the ROS 2 user to specify which DDS provider best fits their needs. As FogROS 2 sets up and secures a VPN for communication between robot and cloud, FogROS 2 needs to configure DDS providers to properly use the VPN. While DDS is a standard, configuring communication in DDS (e.g., ports, discovery protocol) is provider-specific. Similar to how FogROS 2 has a modular cloud-provider system, it also has a modular DDS-provider system. As of this writing, FogROS 2 supports two popular DDS providers, CycloneDDS [35] (the default in ROS 2) and Fast DDS [36].

B. ROS 2 Command Line Integration

In the previous iteration of FogROS, we recognized that users need a general interface to manage their existing FogROS cloud instances and connections. FogROS 2 integrates with the ROS 2 Command Line Interface (CLI), offering an intuitive way to interact with FogROS 2 cloud instances, particularly for users familiar with interacting with other ROS components, such as listing the existing ROS topics. To use the CLI, a user types

```bash
ros2 fog <command> [args...]
```

where command specifies an interaction with FogROS 2 along with one or more arguments. For example, the command can be, list, to list cloud instances, delete, to delete existing instances that are no longer in use, or connect, to connect via ssh [37] to running instances.

C. Streaming Image Compression

Many robot algorithms depend on fast processing of image and video data, and these algorithms increasingly require hardware acceleration e.g., via GPUs. However, images and videos are data intensive, and the time to transmit data to the cloud can reduce the advantage of cloud-based acceleration.

As background, in ROS 2, nodes publish images and videos using a sequence of image messages (Fig. [3] (a)). These messages contain an uncompressed arrays of pixels, which can be very efficient for robot-only processing. However, transmitting even a modestly sized 640×480 RGB image requires close to 921 kB, and transmitting 30 frames per second (fps) would require more than 220 Mbps, making cloud-based processing of high-fps and high-resolution videos impractical. Low-fps or low-resolution image processing of uncompressed images can also suffer from high latency on lower-speed network connections.
The video compression we use is h.264 [38] from the open-source libx264 [39] library. Using this compression allows FogROS 2 to greatly reduce the bandwidth and latency of processing video in the cloud. We implement a ROS2 image_transport_plugin [40] to make the compression transparent to the application—publishing nodes still publish a sequence of images and subscribing nodes still receive a sequence of images—however, in between the publisher and subscriber sits a streaming encoder and decoder. Fig. 3 (b) shows how FogROS 2 implements transparent streaming compression.

H.264 compression has additional benefits: it is popular, well maintained and supported, and often is hardware accelerated, reducing the CPU utilization required to compress and decompress.

D. Remote Monitoring and Visualization

One of the benefits of the secure connection FogROS 2 sets up between robot and cloud is that the cloud machine has a public address that we can leverage to enable remote monitoring and visualization. FogROS 2 integrates Foxglove [5]—a browser-based tool that enables visualization of ROS 2 topics. Much like rviz, the 3D visualizer that is part of ROS, Foxglove operates by subscribing to ROS messages, then interpreting and displaying them. The chief difference is that Foxglove runs in a browser, and thus requires messages to be transmitted over web-based protocols. Thus there are two components to integrate Foxglove with FogROS 2: (1) a Foxglove server, that provides the web interface software, and (2) ROS bridge, a ROS 2 node that subscribes to topics as a ROS node and proxies them through websockets to a browser running the Foxglove software (Fig. 4). When visualizations are enabled, FogROS 2 launches both the Foxglove server as a docker, and the ROS bridge node.

Once set up, FogROS 2 provides the IP address of the server, allowing multiple users in different locations to monitor and visualize the robot application in a browser.

V. Evaluation

We evaluate FogROS 2 in a benchmark on 3 example robot applications where cloud computing can greatly accelerate processing compared to the computing capabilities of the robot. We compare to a baseline of robot-only computing. For examples with cloud-based image processing, we compare to additional baselines of (a) raw/uncompressed, (b) PNG compressed, and (c) Theora [41] compressed, where Theora is an open-source video compression library with an existing image transport plugin [40]. Benchmarks on FogROS 2 use the same computing hardware and thus the main performance difference is due to streaming compression when available.

We use an Intel NUC with an Intel® Pentium® Silver J5005 CPU @ 1.50 GHz with 2 cores enabled and with a 10 Mbps network connection to act as the Robot. We perform all evaluations with cloud nodes deployed to AWS. This setup differs from the examples in FogROS 2 [2], thus results from the prior paper are not directly comparable.

A. Streaming Video Compression

We evaluate the performance of using streaming video compression between robot and cloud. In this experiment, we have the robot node publish images to a topic to which a cloud node subscribes. The cloud node responds immediately with a small acknowledgement message. We record the round-trip time, bandwidth used, and frames per second (FPS), and show it in Table I. From the table we observe the benefit of streaming video compression between the robot and the cloud, as the cloud can receive images 13× faster FPS, while using 26% of the data and shortening the latency to 3% of the original. We observe performance improvement of h.264 over Theora, the previous best available compression, with h.264 requiring 59% of the bandwidth and shortening the latency by 46%. The reduced latency from 1401 ms to 38 ms may enable some real-time cloud-robotics applications not possible without compression.

However, there may be a tradeoff in some applications. Theora and h.264 are both lossy compression algorithms, meaning they are designed to compress videos by discarding some image information. This information loss is tailored to human perception [38], and thus may adversely affect computer vision algorithms.

B. Visual SLAM with Streaming Video Compression

ORB-SLAM2 [42] is a Visual SLAM (Simultaneous Localization and Mapping) library that uses a stream of images to reconstruct an environment map and locate the camera in it. With FogROS 2, we run the SLAM node on...
(a) SLAM w/ h.264 on multicore CPU
(b) Dex-Net w/ h.264 on GPU
(c) Motion Planning on multicore CPU

Fig. 5: Example FogROS 2 robot applications. In (a), the SLAM application streams images to a SLAM node in the cloud using h.264 compression, and publishes a map and localization to the robot. In (b), the robot uses the Dex-Net GQCNN grasp planner on a cloud computer with a GPU to speed up grasp computations from top-down images. In (c), the robot uses a motion planner on a high-core-count cloud computer to reduce motion planning time. Arrows indicate the direction of messages on topics, and blue arrows indicate transparent h.264 video compression.

Fig. 6: ORB-SLAM2 Simultaneous Localization and Mapping. We run ORB-SLAM2 to compute the robot’s location and map out an environment (left) over a sequence of video frames (right).

Table II: ORB-SLAM2 results on FogROS 2. We run ORB-SLAM2 on 3 benchmarks from the TUM Dataset and measure average per-frame round-trip latencies incurred by the ORB-SLAM2 node. Here, FogROS 2 runs on a 36-core cloud computer.

| Scenario | Robot Only | Compressed h.264 |
|----------|------------|------------------|
| fr1/xyz  | 0.52       | 0.82             |
| fr2/xyz  | 0.43       | 0.75             |
| fr2/loop | 0.68       | 0.89             |

Without compressed image transport, the ORB-SLAM2 node is unable to receive and process frames quickly enough to avoid dropped frames. Streaming video compression with FogROS 2 alleviates this issue and reduces overall latency to only about 200 ms, by leveraging cloud compute, less than half the latency incurred by running the node on the robot itself. In contrast, compressing individual images using the available image transport plugins results in over 3 times higher latency as information in successive frames is not leveraged.

C. Dex-Net Grasp Planning on a Cloud GPU

Dex-Net [44] uses a deep neural network to compute grasp contact points given a depth image. This allows a robot to determine the grasp that is most likely to succeed when picking up an object. In this example, since the robot does not have a GPU (or other fast neural network hardware), it gains fast neural network processing using FogROS 2. With FogROS 2, we run the grasp-quality convolutional neural network (GQCNN) (Fig. 7) on a cloud computer with a GPU for fast neural network processing. We record the results in Table III.

Table III: Dex-Net results on FogROS 2. We measure compute time in seconds for 10 trials on a robot with a CPU, and compute and network time using cloud computer with an Nvidia T4 GPU via FogROS 2.

| Scenario | Robot Only | Compute | Network | Total |
|----------|------------|---------|---------|-------|
| Uncompressed | 14.0 | 0.6 | 5.0 | 5.6 |
| Compressed  | 14.0 | 0.6 | 0.7 | 1.3 |
| h.264      | 14.0 | 0.6 | 0.6 | 1.2 |

FogROS 2 gains the performance advantage of a GPU and overcomes the network latency overhead, speeding up grasp computations from 14 s to 1.2 s, for an over 11× speedup. We observe a modest performance advantage of using h.264 over prior compression as each input image changes slightly from prior. Video compression works best when there is continuity between images. In a real-world setting, h.264 video compression will compress better in a scenario when the robot is repeatedly picking objects from a scene with little other change (e.g., a sequence of objects removed from a single bin), and will likely have little-to-no benefit if each scene is brand new (e.g., a sequence of differently cluttered bins).
D. Multi-core Motion Planning on 96 cores

Motion Planning Templates (MPT) [45] is a highly scalable multi-core motion planner that computes collision-free paths between start and goal points. It runs a sampling based motion planner, and with additional cores it can sample more points concurrently, scaling nearly linearly due to its use of lock-free data structures. With FogROS 2, we run 4 motion planning problems (Fig. 8) on a 96-core cloud computer, and record the results in Table IV.

With a high-core-count cloud-computer, MPT is able to significantly out-perform robot-only computation, for example, reducing 157.6 s compute time to 5.5 s compute+network time, speeding up motion planning by up to 28×.

| Scenario   | Robot  | FogROS 2 |
|------------|--------|----------|
| Apartment  | 157.6  | 4.22     | 1.28 | 5.50 |
| Cubicles   | 35.8   | 2.16     | 0.07 | 2.23 |
| Home       | 161.8  | 4.30     | 1.30 | 5.60 |
| TwistyCool | 167.9  | 16.24    | 0.06 | 16.18 |

Table IV: MPT Motion Planning results on FogROS 2

We run multi-core motion planners from Motion Planning Templates (MPT) [45] on 4 motion planning problems from the Open Motion Planning Library OMPL [46] (See Fig. 8). We record the planning time running on a 96-core cloud computer, and the network round-trip time between robot and cloud.

VI. CONCLUSION

We present FogROS 2, an extensible and easy-to-use cloud-robotics platform for running compute-intensive portions of ROS 2 applications in the cloud. FogROS 2 integrates with the ROS 2 launch and communication systems, to provision and start cloud computers, configure and secure network communication, install robot code and dependencies, and launch robot and cloud-robotics code. As a redesigned and distinct successor to FogROS, FogROS 2 supports ROS 2, transparent video compression, improved performance and security, access to more cloud computing providers, and remote visualization and monitoring. In experiments, we observe a significant performance benefit to using cloud computing, with the additional improvement from transparent video compression. Being extensible, FogROS 2 can readily support additional cloud computing providers and DDS implementations. Being easy-to-use, FogROS 2 can quickly improve performance and responsiveness of ROS 2 applications.

In future work, we will continue to add support for additional cloud computing providers and services. We will explore additional models of computing, such as serverless, spot instances, and more. We will also explore extending the networking capabilities of FogROS 2 to allow robots to communicate, collaborate, and share data more easily.

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