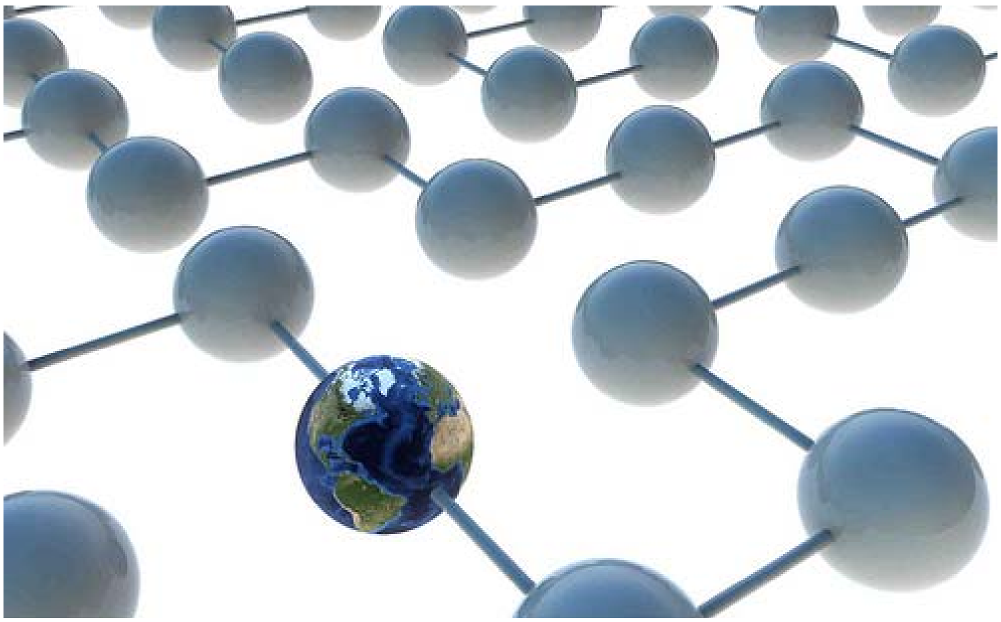
GTCS 2.0:
Opportunities for the Next-Generation Global Tracking and Control System



Enabling real-time machine-to-machine tracking anywhere on land or sea

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The Transformative Impact of M2M

Since the invention of the telegraph in the 19th Century, telecommunications have been linking distant places and allowing information to flow from one to another. In the 21st Century, a fast-rising percentage of that telecommunications is taking place between devices without a human being in the loop. Machine-to-machine (M2M) communications allows us to equip the world with inexpensive sensors and feed IT systems useful information on temperature, tension, light, electrical properties, the presence of chemicals or biological agents and much else. Location, speed, duration and condition can all be monitored in real time by sophisticated systems that do not have to be installed in the thing being monitored. They can provide a global view of infrastructure, of moving objects or of the movements of people carrying those objects, and help us manage them far more effectively.

These remarkable capabilities explain why Infonetics Research expects there to be 428 million cumulative mobile M2M connections by 2014, reflecting a compound annual growth rate of 38%.[1] Analysis Mason expects there to be 2.1 billion M2M devices installed worldwide by 2020.[2] The total revenue generated by connected devices will grow from US$560 billion in 2010 to US$1.8 trillion in 2020, according to Machina Research. [3]

They also explain why the maritime industry is expected to be one of the biggest beneficiaries of this technology revolution. M2M is already embedded in oil & gas exploration vessels and production platforms at sea, because the high value of the end product has made it easy for companies to justify significant investment in sensors, communications and analytics. With technology and communications costs falling, the world's merchant fleets are following in their footsteps. From monitoring the condition of refrigerated cargo around the clock to troubleshooting electronic or mechanical systems, M2M will have a major impact on the quality, reliability and productivity of sailing vessels.

Navigating the Crowded Airwaves

As with any big transformation, however, you can expect bumps in the road. For maritime M2M, one of the biggest bumps is radio frequency spectrum. Sensors placed aboard ship can be hard-wired and have no need to go wireless. But many of the most commercially useful applications will need a wireless connect. In a recent project, Globecomm worked with a major wireless technology company to place sensors that continuously measure the condition of valuable cargo throughout a major fleet. The cargo containers connect to a shipboard server over standard GSM mobile phone frequencies.

That's no problem when the ship is at sea. But as it comes within range of land-based mobile networks, it encounters issues. The sensor mobile network is not licensed in that nation and its signals are not meant to traverse the national network. To avoid interference, national regulations require an immediate change: either switching off transmitters or attenuating the signal based on the ship's location and spectrum restrictions that are specific to that nation.

Meeting this challenge is technology called the Global Tracking and Control System (GTCS). It links the ship's GPS receiver to software running on a shipboard server to provide automatic management of wireless base stations and to log all activities and transmit hourly updates of each ship's position and operational status via email to an operations center. It is based on the concept of a "geofence" – an imaginary polygon in which the ship is located, similar to a mobile cell. As a ship moves from polygon to polygon, the GTSC determines the mobile spectrum rules for that particular location and adjusts the local network as needed.

GTCS works within the narrow scope of its original design. But as the volume of M2M traffic traveling over shipboard mobile spectrum grows, it will be increasingly challenged to keep up. Expanding requirements call for additional features and functions, such as support for multiple fleets where each has its own tracking and set of geo-fence bounds. Currently, supporting multiple fleets with GTCS requires multiple instances of the GTCS server. While this approach works, it also increases the operational and maintenance costs of the GTCS system – something that nobody wants to see.

The Next Generation of GTCS

To prepare for a robust M2M future, Globecomm has implemented a major modification to the GTCS architecture, by integrating it with a commercial off-the-shelf product called SpatialRules® by TransVoyant. The result is GTCS 2.0, which offers the flexibility and scalability required to meet rising demand for mobile M2M networks at sea.

This white paper explores the GTCS and SpatialRules technologies, describes their integration, and outlines the future opportunities that GTCS 2.0 make possible.

A Better Polygon

Specifically, SpatialRules GTCS provides the GTCS system with a more precise representation of national water boundaries. Most water boundaries are set at 12 nautical miles (nm), which represents the turn-off and turn-on points for the ship's GSM transmitter in most cases. But there are exceptions. For example, in the case of Italy, the required system behavior at 2 nm and 3 nm as well as 12 nm differ from the standard 12 nm turn off or turn on. Total shut-off in this case does not happen until the 2 nm point. The SpatialRules implementation makes this possible by allowing custom rules specific to a jurisdiction.

Updating the GTCS architectural framework also makes it easier to add extended features and capabilities, making it possible to:

- Provide an alerting handler system that can support changes to the alerting parameters during run time
- Base alerts on the standard GSHSS (Global Self-consistent, Hierarchical, High-resolution Shoreline (GSHHS) shape files published by NOAA, effectively dropping the requirement for custom geo-fence polygons
- Provide an extensible application framework that can easily accept new geospatial tracking and status alerts such as when:
  - A ship deviates from a planned route
  - The number of ships in a geospatial bounds either exceeds or falls below a configurable parameter
  - A ship is within defined proximity parameter of another ship known to operate a GSM transmitter on a competing spectrum
- Support changes to the rules base and alerting configuration during run time

Opportunities for Next-Generation GTCS

The first generation of GTCS is a location-aware M2M application. It generates alerts to involve human operators only when the conditions requiring human intervention exist. Meanwhile GTCS 1.0 maintains detailed log files along with near real time position and status awareness.

But as a first generation system, GTCS has not taken advantage of mature geospatial application platforms or even the most rudimentary pattern-matching algorithms common to most business rules systems. What GTCS 1.0 represents is an idea. That idea is to generate location-based alerts to provide routine and exceptional management of a communications system. GTCS 2.0 offers both near-term and long-term benefits that open up completely new opportunities.

In the short term, a simplified architecture will cut the maintenance overhead for GTCS by at least 50%. Longer term, it opens the door for new business opportunities that could lead to a global tracking service.

For example, consider a multi-million dollar piece of mining equipment at a remote site. The owners of the equipment would like to stay informed about the location and status of their investment. The remote area would have no cellular communications. Establishing a satellite ground station with a

BTS would create a local GSM environment. The equipment has installed a GSM device with a GPS and other embedded status and control sensors as desired. A server hosted in a central location could then manage location-aware tracking services for equipment located worldwide. The owners could receive alerts on their personal devices in near real time whenever the location or operational status of the equipment deviates from allowed parameters.

Inside the Technology

GTCS

GTCS is a three-tiered M2M application consisting of the GTCS server connecting to the Shipboard Global Positioning System (GPS) unit and the middle tier Base Station Controller (BSC) connected to the BTS located on each ship.

GTCS software architecture includes Java SE technology, Oracle database, and PHP scripting language. There are four Java modules: Location Handler, Geofence Device Handler, Provisioning Handler, and Alarm Manager. There is also the GTCS Repository (an Oracle database), and Admin Handler (provides graphical web interface to GTCS).

GTCS modules communicate by creating, exchanging, or acting on a Service Request. The Location Handler and the Geo-fence Device handler issue service requests to the provisioning handler for execution. There are two types of service requests: location update and BTS commands. Location update service requests are for retrieving GPS coordinates from operational vessels. BTS command service requests control the power of the BTS onboard a vessel. GTCS consists of the following modules, as shown in Figure 3-1.

Location Handler

The Location Handler issues service requests to a vessel for its location. Once a vessel returns GPS coordinates, Location Handler inserts the coordinates along with speed and heading data into the GTCS database.

Geofence Device Handler (BTS Manager)

The Geofence Device Handler (GDH) correlates the vessel's current location to the spectrum requirement of the polygon it occupies. GTCS then sends the appropriate BTS service request to adjust the state of the onboard BTS.

Provisioning Handler

The Provisioning Hander is comprised of In and Out Mediation components that manage communication between the GTCS database and the Provisioning Handler. The In Mediation component utilizes a system loop to check the GTCS database for new service requests and passes outstanding requests from modules to the Request Processor. Out Mediation also handles communication between the GTCS database and Provisioning Handler. However, Out Mediation updates service request status after the Provisioning Handler fulfills service requests received from other modules.

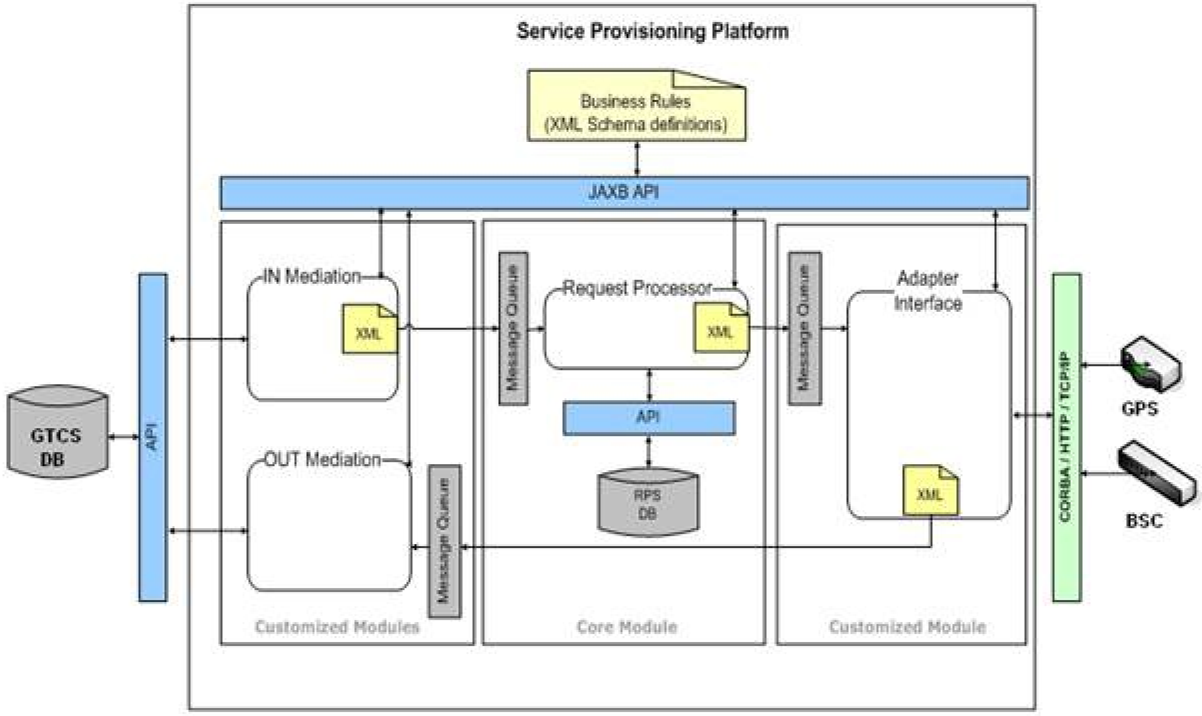

Figure 3-1 GTCS Logical Component Diagram

Request Processor

The Request Processor processes service requests fetched by In Mediation. Request Processor software module loops every second to check for outstanding service requests. The Request Processor checks network type and request type to determine the actions needed to fulfill the request. GTCS generates the appropriate MML commands and passes them on to the Adapter Interface to communicate with the client located in the vessel. There are currently five different adapters. GTCS only uses two adapters: Moxa GPS module and Ericsson BSC module.

Adapter Interface

The Adapter Interface receives instructions from Request Processor on how to communicate with vessels. The Adapter Interface checks the adapter type needed to communicate with the vessel, and then executes the command accordingly. Each adapter has its own way of communicating with the vessel. The most common adapters are either VSAT or Inmarsat uplinks.

Admin Handler

The Admin Handler provides a graphical user interface (GUI) to GTCS users via a web browser. Admin Handler uses PHP pages, supported by Zend Core. The Admin Handler queries the GTCS Repository to retrieve vessel data.

GTCS Repository (Oracle DB)

The GTCS Repository is the GTCS database implemented in Oracle. This database stores the national water polygons created using Google Earth and exported as KML files. The Polygons in KML format are imported using the interface provided in the admin web interface.

Alarm Manager

The GTCS Alarm Manager provides system health monitoring services. The Alarm Manager checks a table in the GTCS repository for alarm records generated by other modules. Alarm Manager activates only when there is a fatal error in any of the modules. It then determines the severity of each alarm and sends out notices via e-mail or SMS.

TransVoyant SpatialRules®

The following section uses material from the TransVoyant white paper "Complex Event Processing forSpatial and Temporal Data". A copy of the full original white paper is available from TransVoyant.

TransVoyant SpatialRules is a Complex Event Processing (CEP) engine designed for continuously analyzing large volumes of time-stamped location data and transforming data into useable information. Varieties of industries use CEPs for monitoring and alerting on continuous streams of information. For example, CEPs are used to monitor credit card transactions for fraud and abnormal usage. CEPs are also used for automated trading to establish conditions such as timing to execute buy and sell transactions.

SpatialRules applies CEP concepts to spatial and temporal data. Rules, written in a script language, define patterns, events, and conditions of interest. These rules apply to continuous streams of data containing spatial and temporal information in order to provide tipping, cueing, and alerting when rule conditions resolve to true.

Examples include monitoring vehicles to detect when they enter or exit an area of interest, veer off- route, or move within proximity to a landmark or other moving objects. Cluster analysis indicates when certain types of objects gather near each other. Zone monitoring detects when populations in an area exceed or follow below defined thresholds.

Geo-fencing and proximity to areas of interest can be monitored in two or three dimensions to establish threat zones, monitor airspace, or detect transitions across checkpoints on the ground, at altitude, or below sea level. Areas and corridors can be monitored for undesirable activity or to warn when severe weather approaches work zones, crews, or convoys. SpatialRules supports the following conditions:

Core Capabilities	
Enters	An object enters an area of interest.
Exits	An object exits an area of interest.
Crosses	An object crosses over a boundary or line.
Intersects	The geometries of two or more objects intersect with one another.
Overlaps	The geometries of two or more objects overlap one another.
Within Proximity	Two or more objects come within a distance of each other.
Within Proximity in Time Window	Objects come within distance of one another and their collection times do not exceed a specified threshold.
Within	An object is within the bounds of another object's perimeter.
Cluster	Two or more objects form a cluster based on proximity, number, and type of objects.
Density in Time Window	The population of a defined area exceeds a specified population within a specified time window.
During	A condition exists within a segment of time. The segment can be absolute or recurring.

Streams of location-attributed information often do not have well-defined start and end points. To process this type of data, data elements are analyzed incrementally as they are collected. This approach detects many events that might otherwise be difficult or impossible to discover using manual techniques.

Business data can be added to focus the analysis on specific kinds of data, such as the following:

- Type of material being carried
- Intended destination
- Worker status
- Opening of a secure container outside a designated area
- Watch-list items

Data Flow

TransVoyant SpatialRules is a commercial off-the-shelf (COTS) product that integrates with applications to provide continuous analysis of spatial and temporal data. Rules are created to filter data and discover information as the data is analyzed. When events are discovered, the results are placed onto an event queue to be sent to subscribing parties. Subscribers could also be client applications, queues, web services, or databases. The information flow is shown in Figure 3-2.

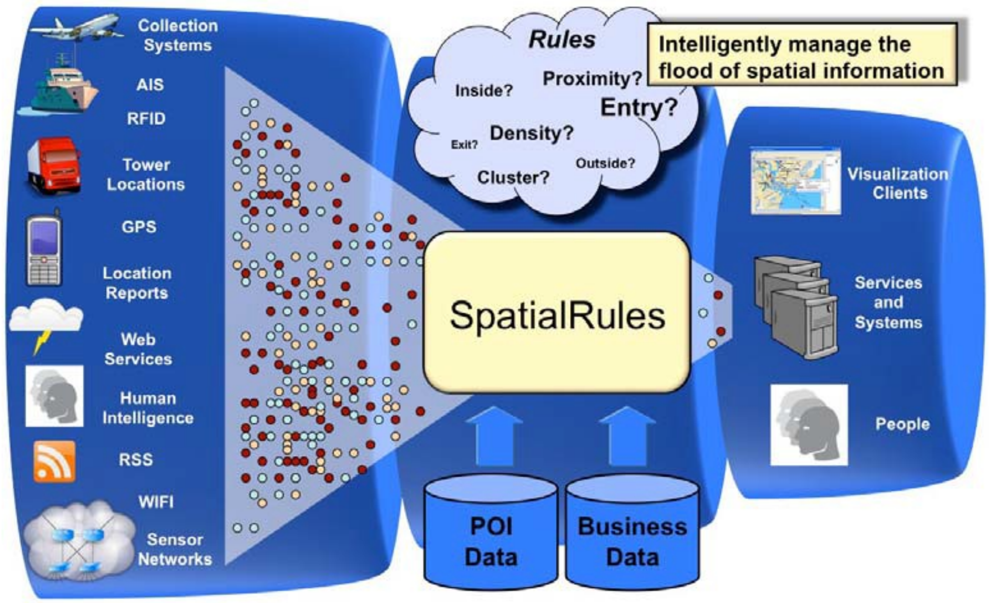

Figure 3-2 Data flow through SpatialRules

Data is analyzed in real time, as it is collected, to detect object interactions over time. Alternatively, historical data could be played and replayed, refining the rules with each pass, to drill deeper into a given situation or explore what-if scenarios.

Analysis is performed incrementally, on fine-grained pieces of data, such as a GPS position, an RFID event, or a sensor reading. Each of these fine-grained pieces of data is organized, evaluated and tracked within the context of all the other fine-grained pieces of data that are collected and tracked.

Conventional Solutions

The benefits of geo-fencing and proximity alerting are well known. However, current implementations exist mainly as custom applications that address a specific set of capabilities. The next sections discuss some techniques that have been used to monitor spatial and temporal data and why TransVoyant SpatialRules provides greater flexibility and capability.

Business Rule Engines and Database Techniques

Continuous data streams have no well-defined start and end. Data must be processed incrementally as it is received. For example, each GPS position of a vehicle must be compared to all other relevant data previously collected. A business rule engine has no way of reducing the scope of analysis as each fine-grained data element is received. As a result, scalability problems can occur with large amounts of data.

Another conventional solution for analyzing spatial and temporal data is to use a relational database. This approach works well for data mining activities. However, while databases are efficient at storing and retrieving data, they are not well suited for monitoring continuous streams of information. Complex Event Processors, like SpatialRules, invert the relationship between the data and a query such that each piece of data matches itself to the appropriate queries (or rules, using the SpatialRules terminology). In most cases, the data matches only a subset of available rules. This provides a mechanism for evaluating only the rules that apply to a piece of data. For example, expressing a simple rule requires the following:

"Object-A *exits* Zone-3"

To express this rule using SQL database techniques, the following statements must be satisfied:

- Insert incoming location report for Object-A
- Query the last 2 locations reports for Object-A (P and P-1)
- Query Zone-3 and check if P is outside and P-1 is inside (transitioned from inside to outside the zone)

A primary challenge in dealing with continuous information streams is addressing the potential combinatorial problem of matching new input to everything in the database. SpatialRules uses the inverted data-query relationship mentioned previously to reduce the set of applicable rules for each piece of new data. Only rules that could potentially return true are evaluated. Using database techniques where queries execute to resolve rules does not offer a means for reducing the number of queries executing for each piece of data.

For example, a location reported in Manhattan would never trigger a rule about objects entering a boundary around Los Angeles. SpatialRules is able to avoid the evaluation for the Los Angeles rule since the data doesn't qualify for that rule. This is because the data didn't match the rule and self- determined the rule is out of scope. However, a query-driven approach has no choice but to answer the question by evaluating the query.

While database techniques might be possible in some scenarios, it's likely that this approach will be batch-like in nature, periodically evaluating queries for conditions of interest. As the system grows, scalability is likely to become a problem. Additionally, if the rule logic is programmed in SQL or the application, new rules and algorithms incur development costs and deployment risks.

TransVoyant SpatialRules provides the ability to express rules concisely and alter rules without restarting the service. Because SpatialRules is designed to process spatial and temporal data, rule evaluation is fast and efficient while providing a more flexible solution overall. New and more advanced capabilities can be introduced without incurring development risks.

TransVoyant SpatialRules is a middleware service that acts as a filter between source data and an application or service using the source data. The architecture is divided into three parts, including inputs, outputs, and configuration. This approach enables rules to filter and analyze data to identify conditions, reduce the amount of noise, or route information to an appropriate destination. A high-level architecture diagram is shown in Figure 3-3.

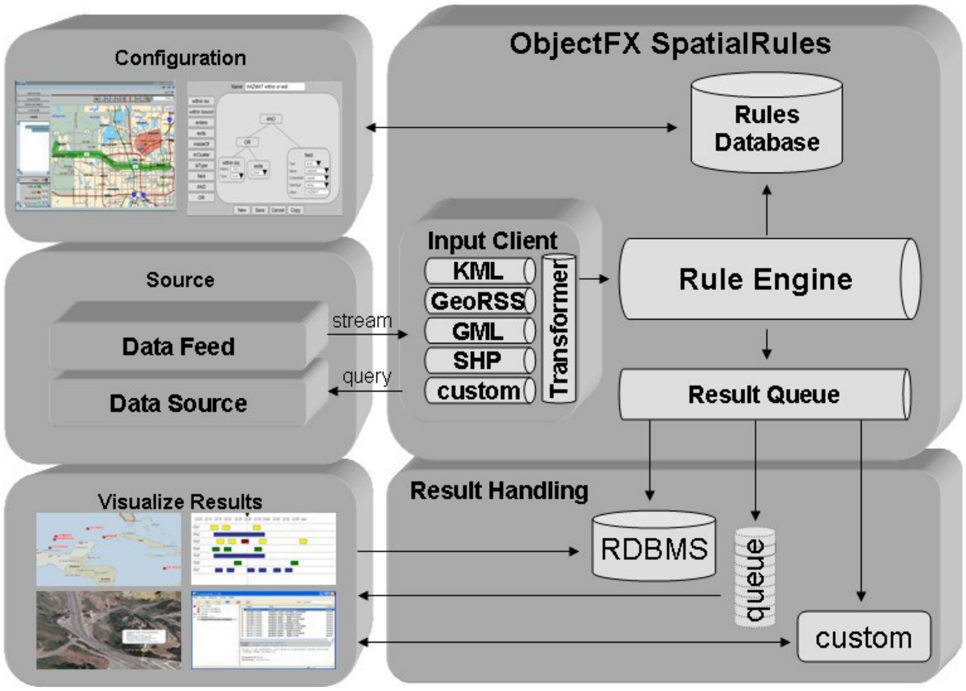

Figure 3-3 TransVoyant SpatialRules High-Level Architecture Diagram

The following table describes the core pieces of the SpatialRules architecture:

High-Level Components of SpatialRules	
Input Client	Receives streams of data or periodically queries a data source and transforms the contents for analysis. This component is typically how an application feeds data to the rule engine service.
Rules Service	Performs analysis and posts results to the result queue. This component is typically started as a service.
Result Queue	Interfaces between the rule engine and the integrating applications and services that receive the output from SpatialRules.
Rules Database	Stores the reference features and rules used at runtime. This component includes the interface for managing features and rules.

Integrating SpatialRules into GTCS

Taking all of these technical features into account, Globecomm has embedded SpatialRules into GTCS to create a new system that also supports satellite uplink and wireless data communications. While the core GTCS architecture remains, SpatialRules replaces modules that use hand-drawn national water polygons and provides direct use of the NOAA GSHSS world shoreline data sets or other spatial reference data as needed by customer requirements. A configurable proximity rule with respect to the shoreline generates the alerts for the BSC to change the BTS status.

This integration makes it possible for next-generation GTCS to greatly expand the functionality of the system. It enables the development and implementation of custom rules that offer greater ability to generate alerts with finer granularity, such as:

- Alert when a ship deviates from the planned route
- Alert when a high cost item with its own GPS enters a shoreline indicating it is no longer on the ship
- Alert specific to a named geographic feature
- Alert specific to a specific ship by name
- Alert that applies only for member of a named fleet or specific class of ship
- Alert when any number of locatable object fall above or below a count inside or outside of a geospatially defined area
- Alert in response to any situation involving time or location with respect to any dynamic or static locatable object

Next-generation GTCS supports worldwide tracking and status for air, land, and sea. Anything that can transmit can be tracked.

Key Changes in GTCS 2.0

SpatialRules uses geometries and other information to evaluate data using rules that are comprised of *predicates*. Geometry is a locatable object that has geometric characteristics such as a point, line or space. Predicate statements can be logically joined using AND, OR, and NOT Boolean logical operators.

Reference Data

Geographic features are loaded into SpatialRules as reference data. As a result, rules reference features directly by name. Examples of reference features include the following:

- Political boundaries
- Road segments
- Landmarks
- Territorial waters

Reference features typically do not often change and they can modified, added, and deleted without restarting the service.

The primary GTCS reference feature is the GSHHS world shoreline data provided by NOAA. The shoreline data set will be loaded into the SpatialRules repository during configuration of the GTCS system. Updating the shoreline data can be refreshed easily whenever NOAA or other data source publishes an update. This is an infrequent event occurring at the most once or twice per year.

Dynamic Data

Data analyzed by SpatialRules is generally dynamic in nature in that it is moving, changing shape, or interacting with other dynamic objects. Some examples include the following:

- Vehicles
- Aircraft
- Vessels
- Weather systems
- Shifting protection zones
- Work zones
- Incident reporting
- Docking locations and schedules

Data submitted as a *dynamic feature* is processed against a set of rules. SpatialRules generates a result when a rule evaluates to True. That result is posted to a *result queue*. The next two sections briefly explain this process.

Inputs

GTCS Ship location Data enters the SpatialRules repository using the DynamicFeature class. Dynamic features pass directly to SpatialRules for evaluation. The rules can be configured to process multiple input sources at the same time. An example of concurrent multiple-source analysis is shown in Figure 5-1, with each dynamic feature supporting a minimum set of fields that includes:

- ID
- Type
- Location
- Date and time the data was captured

Additional data may be included as name-value pairs. The additional data can be used by the rules you define for further filtering capability.

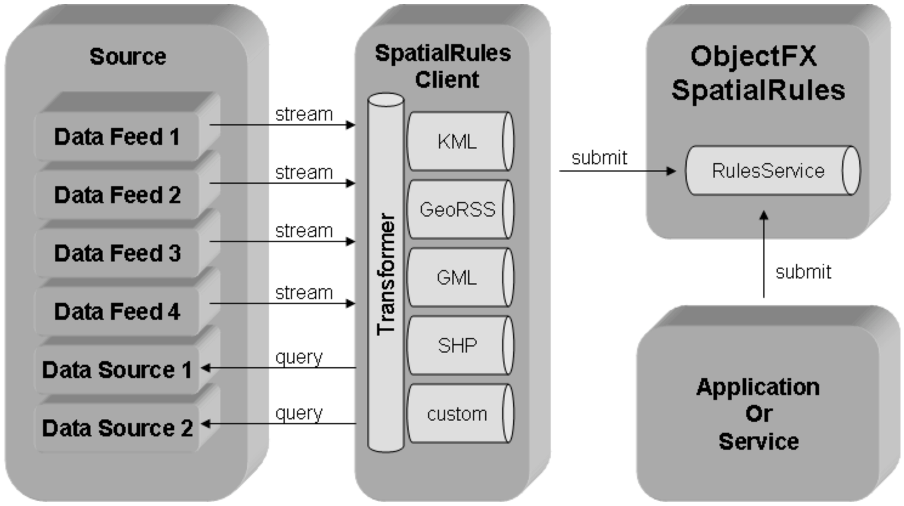

Figure 5-1 Concurrent Multiple-Source Analysis

Outputs

As input data is processed, any rules that evaluate to True produce a Result object. Results are posted to a result queue. The result object are evaluated and acted on by the BTS Handler.

Result Structure	
Expression Name	Name of the expression (rule) that evaluated to True.
Subject	The dynamic feature that triggered the rule evaluation.
Target Set	The set of targets used in evaluating the rule. A target might be a dynamic feature or a reference feature. A target set might include a mix of both types depending on how the rule is specified.
Date	The timestamp when the result is created.

This result object contains sufficient information for evaluation by the handler class and invocation of the correct BTS state.

About Globecomm

Globecomm is a leading global provider of managed network communication solutions. Employing our expertise in emerging communication technologies, we are able to offer a comprehensive suite of system integration, system products, and network services enabling a complete end-to-end solution for our customers. We believe our integrated approach of in-house design and engineering expertise combined with a world-class global network and our 24x7 network operating centers provides us a unique competitive advantage. We are now taking this value proposition to selective vertical markets, including government, wireless, media, enterprise, and maritime. As a network solution provider we leverage our global network to provide customers managed access services to the Internet backbone, video content, the public switched telephone network or their corporate headquarters, or government offices. We currently have customers for which we are providing such services in the United States, Europe, South America, Africa, the Middle East, and Asia.

- We offer a wide range of hosted and managed communications services that leverage our global transmission capacity and our network of data center, content management and switching facilities.
- Our expert teams can also advise you on the best ways to meet your critical communications needs, while our specialized laboratories evaluate broadcast, IP and other technologies for customers.
- We can engineer and integrate individual systems or complex networks, and then support them through the lifecycle.
- Our engineering expertise has also produced a wide range of satellite and wireless terminal products ready for quick and cost-effective deployment.

Globecomm makes one vital commitment to our customers: that the solutions we provide will work, no matter what. Founded by engineers, Globecomm provides services and products supported by one of the industry's largest in-house engineering staffs. When we build components into our services and products, you can count on the fact that we have tested them exhaustively for reliability, compatibility and cost-effectiveness. That's why suppliers have come to rely on us for improvements to the products they provide.

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[1] "Exponential Growth in M2M Market Dependent on Important Network Enhancements" by Alan Weissberger, *Viodi View*, October 7, 2010

[2] "The Internet of Things Comes Alive" by Jane Bird, *Financial Times*, November 15, 2011

[3] *The Connected Life*, GSM Association, 2012.