NMEA Communication Standard for Shipboard Data Architecture

NMEA komunikacijski standard za arhitekturu podataka na brodu

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Summary

The paper describes a computer network of an integrated navigation system on board the ship using NMEA 2000 standard, which is primarily designed to provide two-way communication between the ship's navigational equipment such as radar, GPS receiver, AIS, Gyro compass etc. NMEA 2000 is based on CAN which is standardised by ISO. ISO 11898 specifies physical and datalink layer of serial communication technology called Controller Area Network that supports distributed real-time control and multiplexing. This paper presents a comparison of the NMEA 2000, which is based on CAN, with popular Ethernet protocol, which is currently used as a basic protocol in the LAN. The physical, datalink and application levels of the NMEA 2000 computer network are described. Finally, the marine electronic equipment of modern ship which is integrated in navigational system using NMEA 2000 is shown. NMEA 2000 standard became international standard under IEC.

KEY WORDS

Integrated Navigation System (INS)
Serial Communication Protocol
Nmea Standard
Real-Time Control onboard the Ship
Integrated Ship Control Network

Sažetak

U članku se opisuje računalna mreža za integriranu navigaciju broda koja se koristi NMEA 2000 standardom, prvenstveno razvijenim za osiguranje dvosmjerne komunikacije između brodskih navigacijskih uređaja kao što su radar, GPS prijamnik, AIS, Gyro kompas i drugi. NMEA 2000 se temelji na CAN protokolu koji je sastavljen u skladu s ISO. ISO 11898 definira fizički i podatkovni sloj za serijsku komunikaciju zvanu CAN koja osigurava distribuiranu kontrolu u realnom vremenu i multipleksiranje. U članku se uspoređuje NMEA 2000 s popularnim Ethernet protokolom koji se uobičajeno susreće u lokalnoj mreži (LAN). Opisani su detalji fizičkog, podatkovnog i aplikacijskog sloja za NMEA 2000. Na kraju je prikazan integrirani navigacijski sustav za suvremene brodove temeljen na NMEA 2000. NMEA 2000 postao je i međunarodni standard po IEC.

KLJUČNE RIJEČI

integrirani navigacijski sustav (INS)
protokol za serijsku komunikaciju
NMEA standard
kontrola u realnom vremenu za brod
mreža za integrirano upravljanje broda

INTRODUCTION / *Uvod*

NMEA (National Marine Electronics Association), standardised as IEC 61162-3, is a plug-and-play communications standard used for connecting marine sensors and display units within ships and boats. The NMEA 0183 is simply standard for interconnection of GPS receivers and other navigational instruments. NMEA 2000 is based on Controlled Area Network (CAN), which is standardised by ISO. NMEA 2000 standard also became the international standard under IEC (International Electro-technical Commission).

The protocol is used to create a network of electronic devices - chiefly marine instruments - on a boat. Various instruments that meet the NMEA standard are connected to one central cable, known as a backbone. The backbone powers each instrument and relays data among all of the instruments on the network.

Examples of marine electronic devices to include in a network are GPS receivers, auto pilots, wind instruments, echo sounders, navigation instruments, engine instruments, and nautical chart plotters. The interconnectivity among many instruments in the network allows, for example, the GPS receiver to correct the course that the autopilot is steering.

NMEA 0183 is still a valid standard as a support for the single transmitter/multi receiver serial bus. Data transfer rates do not exceed 4,8 kbit/s. NMEA 0183 is standardised by an IEC 61162-1 and for higher transfer rates by IEC 61162-2.

NMEA 2000 is IEC accepted as a standard IEC 61162-3 on IEC technical committee 80, working group 6 (digital interfaces) and successfully develops another LAN (Local Area Network) standard for ships where LAN requires high capacity and also high security (IEC 61162-4).The replacement standard for NMEA 2000 which might arrive in the next years will probably be an optical standard [12].

Layered model of data network / *Slojeviti model podatkovne mreže*

As the standardised (ISO 7498) Open System Interconnect (OSI) model shows, the NMEA 2000 network connected devices are multiple accessed from the network. Layered approach of the OSI reference model divides requirements into similar-purpose groups. Layers of the architecture are meant to be stand-alone. Communication takes place between adjacent layers; see OSI reference model with seven layers [4].

Layers from application down to session layer are all application oriented in the sense they are responsible for presenting the application to the user or to the certain electronic device. Layers above are independent of the layers below them and are not dependent to the means by which data gets to the application.

The lower four layers deal with the transmission data, covering the packaging, routing, verification, and transmission of each data group. The lower layers are insensitive to the type of data they receive or send to the application, but deal simply with the task of sending it. They also do not distinguish between the different applications in any way.

Layered shipboard data network architecture / *Slojevita arhitektura podatkovne mreže na brodu*

The first version of shipboard data architecture was developed during the MiTS project (Rødseth Ø.J., Øgård O., Hallset J.O., Haaland E. 1992) using four layers: Instrument, Process, System and Administrative. MiTS was developed as an integrated ship control (ISC) protocol which could integrate, e.g., a NMEA network on the bridge with industrial data network in the automation system, e.g. Profibus, CAN network. The most recent version introduced a general ship layer, which integrates the administrative layer, and finally an off-ship layer. A MiTS (Maritime Information Technology Standard) network is similar to Ethernet and originates from Norwegian initiative. Based on the new standard IEC 61162-4, MiTS addresses the requirements of the coordination of wide frequency band devices. MiTS network will be capable of data transfer rates up to 100 Mbit/s. Data transfer rate in MiTS is limited by the bus length, internal delays and clock generator accuracy, which is usually not specified.

The instrument layer is an industrial field bus (NMEA 2000 or NMEA 0183) which serves to interconnect relatively simple devices. Each network on this layer would typically cover a limited number of devices, dependent on physical area and function. Several isolated instrument networks may be used to implement redundant process segments, e.g., to implement redundant propulsion or steering systems. An instrument network may or may not support redundancy itself.

The next layer is the process layer which is used to integrate all functionalities in one process segment, e.g., navigation, ventilation or engine control. Again, redundancy may be required and this could be done by implementing two independent process networks, by supplying redundancy in the network itself or both.

The top layer in the trusted part of the system is the Integrated Ship Control (ISC) layer. This is used to interconnect different process segments as required and also to bridge over to administrative functions where this is needed. As the ISC layer potentially connects to all process segments, one single error on the ISC layer may propagate down into several systems if no safeguard is put in place. Thus, one will need some form of gateway (GW) or Firewall (FW) between the ISC layer and each of the process segments, see fig. 1.

NMEA STANDARD

NMEA stands for National Marine Electronics Association (of the USA). NMEA 0183 was first introduced in 1983 as a voluntary industry standard for data communications among shipboard electronic devices. It uses a simple ASCII, serial communications protocol that defines how data is transmitted in a "sentence" from one 'talker' to one or more 'listeners' at a time, and therefore cannot be used to create networks. Data transmission is slow (by today's standard) at 4800 bits/s and the standard does not allow for multiple 'talkers'. However it is still in widespread use and is perfectly adequate for situations where one piece of equipment, for example a GPS, is to be connected to another

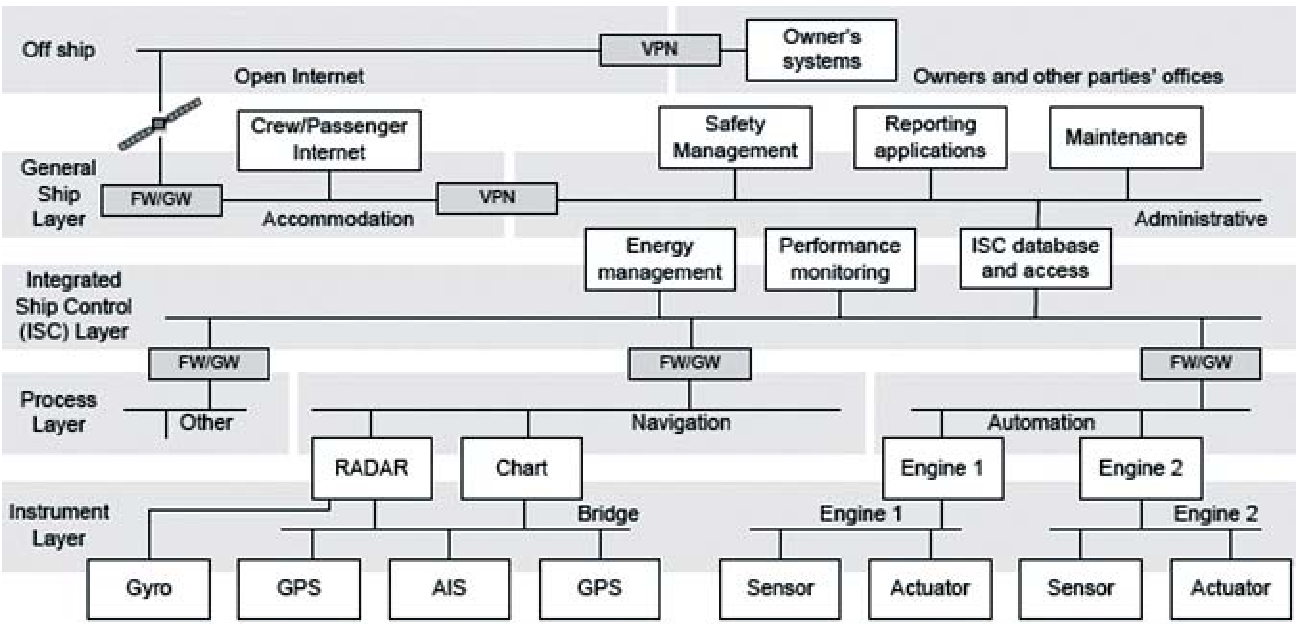

Figure 1 Layer shipboard data network architecture [4]
Slika 1. Sloj podatkovne mreže na brodu [4]

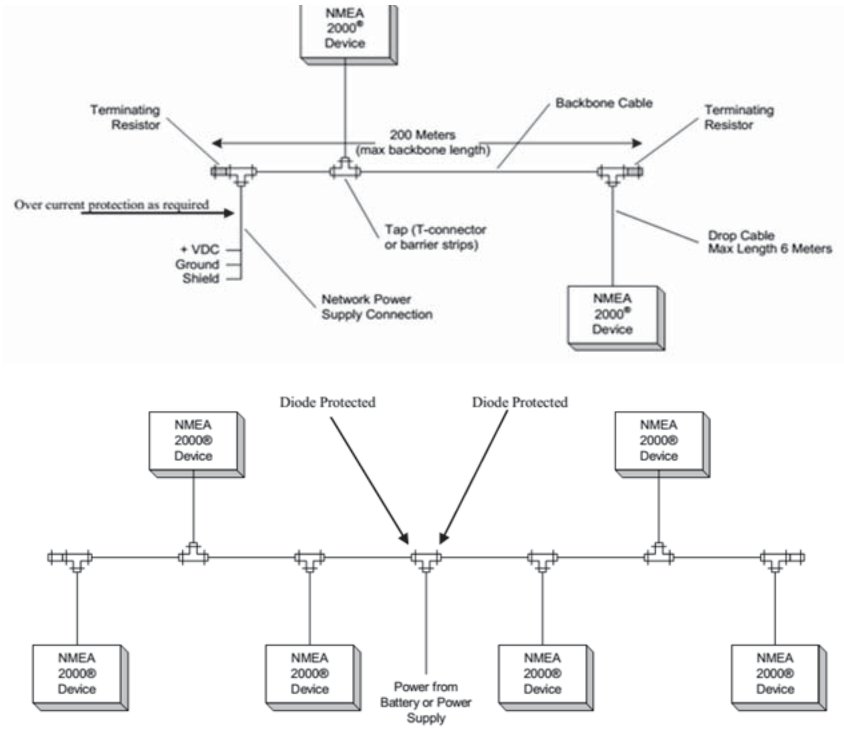

Figure 2 a) Simplistic NMEA 2000 bus topology [4]b) Splitting power on the NMEA 2000 bus [5]
Slika 2. a) Jednostavna NMEA 2000 sabirnička topologija [4] b) Dioba snage na NMEA 2000 sabirnici [5]

such as an on-board chart-plotter where the user wishes to integrate two sets of data.

Different versions of NMEA 0183 were used in the past 30 years, to pass communication between various pieces of equipment. About 10 years ago, NMEA 2000 was introduced to the market. The idea was to create a single wire feed, instead of having many wire feeds and daisy chains from one piece of equipment to another, like a backbone. Each end gets terminated and a power feed is added. Equipment is then added to this "backbone" through a "Tee" connection. Unless the unit requires its own dedicated power supply the backbone provides the power to the unit.

NMEA 2000 is much more sophisticated than NMEA 0183 in that it allows multiple units to simultaneously both transmit and receive data. With the inclusion of multifunction displays into a networked system the user can then choose any combination of data outputs to be displayed at any position or for any situation. It is NMEA 2000 that has made possible the development of the integrated navigation and control systems that are now being fitted on craft of almost every size and application.

NMEA 2000 has a range of advantages over NMEA 0183.The cables carry the information and the supplying energy, reducing both the cabling requirement and the risk of electromagnetic interference (similar to the Power over Ethernet standard). Devices are connected using CAN (Controller Area Network) technology and NMEA 2000 not only allows the transmission of data at significant higher speed than NMEA 0183 (250 kbits/s versus 4,8

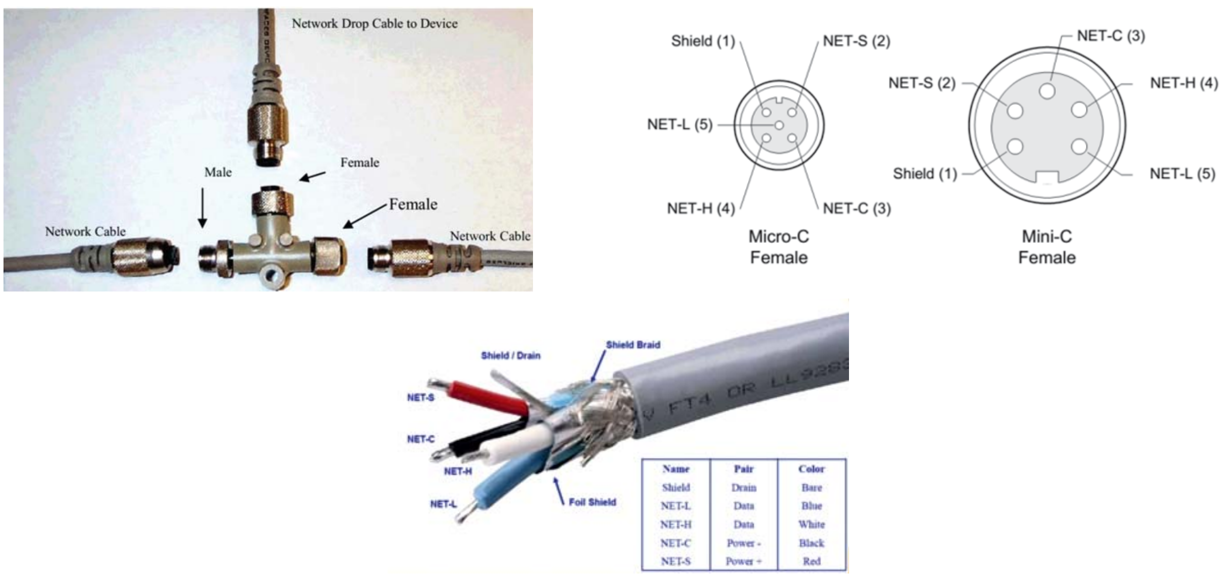

Figure 3 NMEA 2000 standard cable and connector [5]
Slika 3. NMEA 2000 standardni kabel i priključnica [5]

kbit/s), but also in a more compact form, making it far more suitable for complex, multi-unit systems.

The major contemporary components of an NMEA 2000 network are [13]:

- Physical Layer. Fully defined by the standard, including signaling voltages, cables, and connectors.
- Data Link Layer. Defined by ISO 11783-3 with additional requirements specified by the standard.
- Network Layer. To be defined in future versions of the standard.
- Network Management. Defined by ISO 11783-5 with additional requirements specified by the standard.
- Application Layer. Fully defined by the standard and includes a provision for manufacturer's proprietary messages.

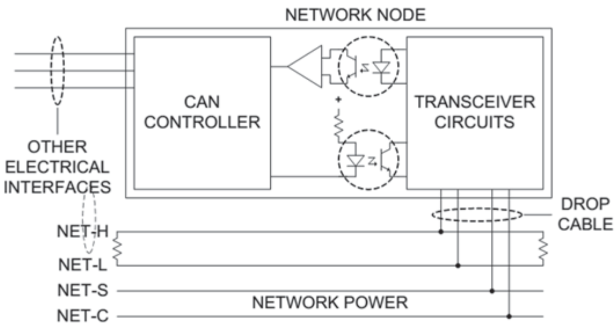

Figure 4 Device Physical Layer Block Diagram [2]
Slika 4. Diagram fizičkih slojeva uređaja [2]

COMPARISON ETHERNET AND CAN (NMEA 2000) / *Usporedba ETHERNET i CAN (NMEA 2000)*

Ethernet is a widely-used cable-based technology for transmitting very large amounts of electronic data between units of equipment within a LAN (local area network) and as such can be found in all forms of computing technology across every aspect of modern life. The Ethernet media include the coaxial system, as well as twisted-pair, and fiber optic systems. The most popular standard today uses the 100Mbit/s Fast Ethernet system which operates over twisted-pair and fiber optic media. The most popular media access control (MAC) protocol on data layer is well known as IEEE 802.3. It plays a valuable role with marine electronics that process high volumes of data, for example radar, electronic charts and weather overlay information, and it is now common to find such units that offer both Ethernet and NMEA 2000 connectivity.

However there is no marine standard for Ethernet and equipment from different manufacturers may not be able to communicate with each other. In addition, unlike NMEA 2000 it does not have the ability to prioritise the transmission of critical data and so is not recommended for applications such as steering or throttle that require a near-instant response, see [17].

CAN (Controlled Area Network) is a communication protocol with high data security implemented by standard integrated circuits. It provides a 'multi-master' transfer protocol for serial communications that includes bit timing, frame formatting, message identification, data transmission, acknowledgment, and error checking. Concept of the 'multi-master' protocol on MAC layer needs a solution like 'what to do if two or more devices simultaneously determine that the bus is not busy and both start to transmit at the same time?' It leads to a bus conflict.

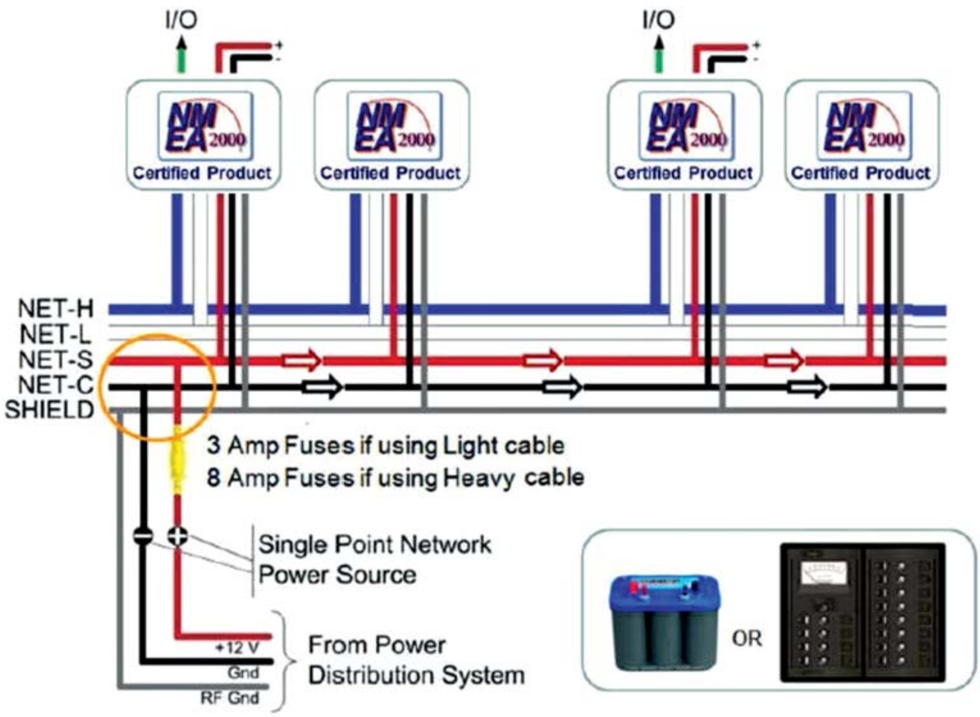

Figure 5 Power supply conection [16]
Slika 5. Spoj na izvor napajanja [16]

There are two different solutions: one for Ethernet and one for CAN. With Ethernet there is a data collision and both devices stop transmitting and try again later, which causes loss of time on the bus and as a consequence the net bandwidth is reduced. With CAN there is an arbitration of bus access on bit-by-bit basis, the device with the highest priority prevails and continues to transmit data, the device with lower priority tries again later.

On the physical level CAN is a peripheral microprocessor developed jointly by Intel and Bosch. This device, which can be compared to the UART that is used at the serial port of all PCs and laptops, and is the input/output mechanism that handles NMEA 0183 / 2000 data for virtually all marine electronic equipment, is attached to or is part of a microprocessor. Current CAN specification is also documented as ISO-11898 (1993) which is written for the manufacturers of the high speed digital networks on board road vehicles [5]. While automotive applications dominate, CAN has exploded also to other applications in all areas of industrial control.

Nearly every integrated circuit company manufactures CAN ICs today.

Much more capable than an UART, the functions of CAN are to:

- Generate the serial bit - stream that is to be transmitted on the network.
- Gain access to the network when the equipment has data to send. It does this by sensing when the network is not busy. If there is a collision with another device trying to put data on the network CAN automatically compares each transmitted bit and arbitrates access on a bit - by - bit basis with Dominant bits winning. With this method there is no wasted network time due to collisions.
- Perform error checking and automatic retransmission of bad messages. CAN also automatically determines when its node has repeated errors and will automatically take a node off - line to protect the rest of the network.
- CAN has no node addresses, because every node receives every message and decides whether to use it or not.

Structure of the ISO 11898 standard:

ISO 11898-1:2003 specifies the data link layer (DLL) and physical signalling of the controller area network (CAN). This document describes the general architecture of CAN in terms of hierarchical layers according to the ISO reference model for open systems interconnection (OSI) established in ISO/IEC 7498-1 and provides the characteristics for setting up an interchange of digital information between modules implementing the CAN DLL with detailed specification of the logical link control (LLC) sub-layer and medium access control (MAC) sub-layer.

ISO 11898-2:2003 specifies the high-speed (transmission rates of up to 1 Mbit/s) medium access unit (MAU), and some medium dependent interface (MDI) features (according to ISO 8802-3), which comprise the physical layer of the controller area network.

ISO 11898-3:2006 specifies low-speed, fault-tolerant, medium-dependent interface for setting up an interchange of digital information between electronic control units of road vehicles equipped with the CAN at transmission rates above 40 kBit/s up to 125 kBit/s.

ISO 11898-4:2004 specifies time-triggered communication in the CAN. It is applicable to setting up a time-triggered interchange of digital information between electronic control units (ECU) of road vehicles equipped with CAN, and specifies the frame synchronisation entity that coordinates the operation of both logical link and media access controls in accordance with ISO 11898-1, to provide the time-triggered communication schedule.

ISO 11898-5:2007 specifies the CAN physical layer for transmission rates up to 1Mbit/s for use within road vehicles. It describes the medium access unit functions as well as some medium dependent interface features according to ISO 8802-2. This represents an extension of ISO 11898-2, dealing with new functionality for systems requiring low-power consumption features while there is no active bus communication.

Outside of office networks CAN is the most used network. CAN is built for real time systems and unlike Ethernet is deterministic. It is inexpensive to implement and is available from a multitude of sources. Its performance is much like existing standards but its cost is much lower. It also consumes substantially less power and requires less space to implement. For real time control of vehicles, there exists no comparable solution that has the same price/performance ratio.

CAN has a small packet size, ideal for sending control information while Ethernet can have very large packets. The disadvantage of course is that small packets are not suited for streaming data or large bandwidth communications. Even so, it

Table 1 Comparison between CAN and Ethernet [2]

Tablica 1. Usporedba CAN i Etherneta [2]

CAN	ETHERNET
CSMA – Carrier Sense Multiple Access with Non-Destructive Bit Wise Arbitration - A Collision less system that is deterministic – Nolost Bandwidth when simultaneous multiple accesses occur.	CSMA – Carrier Sense Multiple Access with Collision resolution Being non deterministic – Bandwidth is lost when collisions occur.
All messages are broadcast	Guaranteed point-to-point delivery - you just don't know when
Bandwidth is constrained by the need for each node to sample the bus at the same time - 62.5Kbit to 1Mbit	Large bandwidth -10Mbit and up
Cable length constrained by the need for each node to sample the bus at the same time – 1,100 meters at 62.5Kbit to 25 meters at 1Mbit	Cable length - 100 metres
Multiple error checks on all transmitted messages - CRC, bit stuffing, and all nodes participate in error checking of each transmitted message	
Automatically determines when its node is having repeated errors and will automatically take a node off-line to protect the rest of the network.	
Guaranteed correct message transmission.	

seems that with care [9], CAN easily handles 2000 messages per second and can possibly handle up to 8000 messages. Testing shows that 2000 messages per second, with sub millisecond response times and guaranteed latencies, are easily achieved. As long as system error handling is not as critical as error detection, CAN is a natural choice [10].

LAYERED STRUCTURE IN NMEA 2000 / *Slojevita struktura NMEA 2000*

Physical layer / *Fizički sloj*

There are two sizes of cabling defined by the DeviceNet/ NMEA 2000 standard. The larger of the two sizes is denoted as "Mini" (or alternatively, "thick" or ''heavy") cable, and is rated to carry up to 8 amperes of power supply current. The smaller of the two sizes is denoted as "Micro" (or alternatively, "thin" or ''light") cable, and is rated to carry up to 3 Amperes of power supply current.Mini (heavy) cable is primarily used as a "backbone" (or "trunk") for networks of larger vessels (typically with lengths of 20 m and above), with "Micro" cable used for connections between the network backbone and the individual components. Networks on smaller vessels often are constructed entirely of "Micro" (light) cable and micro connectors.

There is a formula that can be used to calculate the voltage drop on the network due to the distance between NMEA devices to make sure that you don't have a voltage drop of more than 3,0 Vdc. One of the numbers required in the formula is network load. Network load is the sum of Load Equivalent Numbers (LEN) between the battery and the end of the network. The LEN for each device should be visible on the device or provided in the documentation for the device. Also it can be checked on the site of the equipment provider.

The actual formula is:

E (Voltage Drop) = R (Cable Resistance) x L (Distance) x Network Load (LEN) x 0,01

Current in the network: I = LEN x 0,050 amp

Also, there are abbreviations:

E = 0,1 x LEN x L(m)x 0,057 (for Light /Micro)

E = 0,1 x LEN x L(m) x 0,016 (for Mini/Heavy)

This formula will let you know if you can place your power cable at the end or in the middle of your NMEA 2000 Network. If there is a voltage drop of more than 3,0 Vdc, you must connect power to the middle of your NMEA 2000 Network.

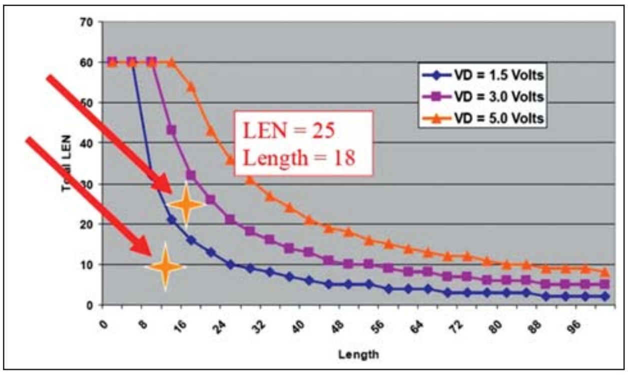

Figure 6 Power supply position in relation of current consumption [16]

Slika 6. Položaj napajanja u ovisnosti o potrošačima [16]

If there is a voltage drop of 3,0 Vdc or less, you can connect your power to either the end or middle of your NMEA 2000 Network. An important cable length optimizing factor for high speed networks is also signal propagation delay.

Also, we can use some recommendations for easy design of NMEA 2000 network:

- Use the "Trunk and Drop" Topology: see fig 7b),
- Determine location for each product,
- Determine path for trunk/backbone that passes within 6 meters of each product,
- Sum of all cables' lengths < 78 meters,
- Determine number and location of power insertion points.

Several manufacturers, including Simrad, Raymarine, Stowe, the Brunswick Corporation and Mastervolt, have their own proprietary networks that are compatible with or akin to NMEA 2000. Simrad's is called SimNet, and Raymarine's is called SeaTalk NG. Stowe's is called Dataline 2000. Brunswick's is called SmartCraft. Some of these, such as SimNet and Seatalk NG, are a standard NMEA 2000 network but use non-standard connectors and cabling; adapters are available to convert to standard NMEA 2000 connectors, or the user can simply remove the connector and make a direct connection.

The NMEA 2000 network is not electrically compatible with the NMEA 0183 network, and so an interface device is required to send messages between devices on the different types of network. Examples include the Maretron USB-100, Simrad AT10 and Actisense's NGW-1. These devices vary in which messages they will translate between the two networks. An adapter such as the Actisense NGT-1-USB,

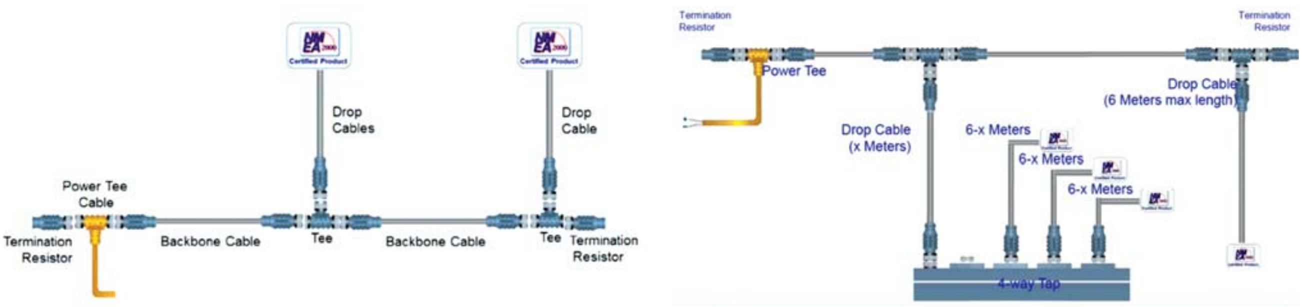

Figure 7 a) Real network segment, b) Max length of each drop must be reduced by the length of the drop cable between the Tee and the multi-tap [16]

Slika 7. a) Segment realne mreže, b) Maksimalna duljina svake grane može se umanjiti za duljinu kabela između T-spoja i multi-priključka [16]

Airmar U200 or Maretron USB100 is also required if NMEA 2000 messages are to be received by or transmitted from a PC.

Components just mentioned make the present characteristics of the NMEA 2000 Network [10]:

- Physical nodes: Up to 50 connections
- Functional nodes: Up to 254 network addresses
- Length: Up to 200m (at 250kbits/s bit rate)

Assuming OSI model, the data transfer of the device according to the NMEA 2000 can reach 250kbit/s. The equipment is able to share data, including commands and status, with other compatible equipment over a single signalling channel.

Data layer / *Podatkovni sloj*

The Controller Area Network (CAN), the basis for the MAC (Media Access Control) acts as a portion of the data link layer (Fig. 5). CAN is a microprocessor peripheral developed jointly by Intel and Bosch. Standardised OSI is richer and more complicated than TCP/IP protocol architecture, which is used for Internet communications and also CAN based SAE J1939 protocol which is used by the NMEA 2000.

Communication between modern devices, which demand wide frequency band such as radar, electronic charts or picture data processors will not be possible by NMEA 2000, even though huge progress in the data transfer rate has been made [see Fig. 1].

Network architecture is not dependent on a central network controller. It is needed to take a control over devices connected to network on a single channel. According to the NMEA 2000 standard each device is its own master of the network and is only dependent on the other devices to follow the same rules.

Data messages are transmitted as series of data frames, each serie with robust error checking and confirmed data delivery. Data frames contain (Fig. 8), in addition to control and error-checking bits, a 0 to 8-byte data field and a 29 bit identification field that sets message priority and identifies the data message, the source and the destination.

NMEA 2000 devices are capable of self-configurable addressing, by which address is determined by internal calculation and then a device's address is requested. Cyclic Redundancy Check (CRC) is a technique in which the frame recipient calculates a remainder by dividing frame contents by a prime binary divisor and compares the calculated remainder to a value stored in the frame by the sending node. CRC sequence of 15 bits seems quite long, but it is optimized for data messages shorter than 127 bits. Five different error check operations are made during every data frame transmission. All checks together can recognize up to 6 errors in a frame. Each message is accepted by all nodes or none. Receivers' hardware acknowledge to the transmitter that there is at least one other functioning node on the network, if ACK bits are not flagged to zero. It is not really the situation that the message has been received [13].

As the actual data content of a data frame is at best 50% of the transmitted bits, this standard is primarily intended to support relatively short data messages which may be periodic. Data messages are transmitted as needed or on-demand by use of query commands. One may say that data content is rather low, but most of marine instruments usually send short data messages. Typical data includes discrete parameters such as position latitude and longitude, GPS status values, steering commands to autopilots, finite parameter lists such as waypoints, and moderately sized blocks of data such as electronic chart database (ECDIS) updates.

Each field of a message shall be defined by table 2.

Network management and application layer /*Upravljanje podatkovnom mrežom i sloj primjene*

The Application layer defines the approved messages, for network management and data messages, that are transmitted on the NMEA 2000 network. Messages transmitted on the network are organized into parameter groups that are identified by a parameter group number (PGN) that appears in the CAN identifier field as either an 8-bit or 16-bit value depending on whether the parameter group is designed as an addressed or a broadcast message. Depending on the amount of data, the parameter group may require one or more CAN frames to transmit the data.

The mechanism for exchanging data between devices connected to the NMEA 2000 backbone is the parameter group. A parameter group is a specific data record containing one or more data fields, or parameters, related to the transmitting device or to the vessel's network. Parameter groups are usually periodic and represent the current parameter values. Receipt of multiple repetitions of the same parameter group from the same device generally denotes a time value sequence of data values and may be used for display or control purposes. Parameter groups are defined in the NMEA 2000 Standard, Appendix B, and are identified by a Parameter Group Number (PGN) that appears in the CAN identifier field along with other information related to the priority, source, and destination of the transmitted parameter group. Since a CAN data frame contains only 8 data bytes, a parameter group may require one or more CAN frames to

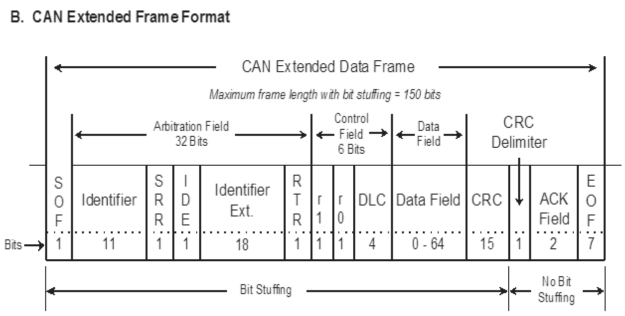

Figure 8 Data frame [4]

Slika 8. Prikaz podataka [4]

Table 2 ID field of data frame

Tablica 2. Prikaz podataka rezerviranih za identifikaciju

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ID field of data frame

26 - 28	Priority	These bits have the most impact during network access arbitration
24 - 25	Reserved	Reserved for future use
16 – 23	Data ID Byte A	High-order byte of the parameter group number of the data being transmitted
08 - 15	Data ID Byte B	• Low-order byte of the parameter group number for global addresses, or • the destination address for non-global data groups
00 - 07	Source Address	Address of the transmitter

Table 3 Data transmitted on the NMEA 2000 network shall be put into standard numerical formats [10]
Tablica 3. Podaci s NMEA 2000 prenijet će se u standardi numerički oblik [10]

Type	Size	Description	Range
bit(n)	n×1 bit	bit field	0 to 1
char8(n)	n´8 bits	8 bit characters, ISO 8859-1 (not limited to ASCII)	Character set
char16(n)	n×16 bits	16 bit characters, Unicode16 Standard (ISO 10646)	Character set
uint8	8 bits	8 bit unsigned integer	0 to 255
uint16	16 bits	16 bit unsigned integer	0 to 65,535
uint32	32 bits	32 bit unsigned integer	0 to 4,294,967,295
uint64	64 bits	64 bit unsigned integer	0 to (264-1)
int8	8 bits	8 bit 2's complement integer	-128 to +127
int16	16 bits	16 bit 2's complement integer	-32768 to +32767
int32	32 bits	32 bit 2's complement integer	-2,147,483,648 to +2,147,483,647
int64	64 bits	64 bit 2's complement integer	-(263) to +(263-1)
float32	32 bits	IEEE 754 single precision floating point	
float64	64 bits	IEEE 754 double precision floating point	
float80	80 bits	IEEE 754 expanded floating point	

transmit all parameters for that parameter group. A parameter group definition includes the following descriptive information:

- Frame Count – Whether the parameter group can be contained within a single 8-byte data frame or must be divided into several frames
- Priority – The default priority of the frame within the system. Parameter groups with higher priority will take precedence over lower-priority parameter groups.
- Periodic Rate – If the parameter group is to be sent periodically, the default rate that the parameter group will be queued for transmission.
- Destination – Whether the parameter group can be sent to a particular address, or if it will always be broadcast to all devices.
- Query Support – The fields within the parameter group that can be queried, whether query support is optional.
- Field Definitions – Each field within a parameter group is defined by name

In order to clearly specify the capabilities of a particular device, manufacturers are increasingly including a NMEA-2000 PGN list to define what data their devices can receive from or send to the network. For NMEA 2000 configuration information on every available NMEA 2000-certified display device, see the owner's manual for your display device.

Application of NMEA 2000 / *Primjena NMEA 2000*

Various physical data are to be communicated on the NMEA 2000 network. Each type of data that is transmitted shall be formatted in accordance to a Table 3. Application Parameters are preliminarily gathered into 44 parameter groups (NMEA 0183 Transport, Navigation data, GNSS satellites in view, Dynamic engine parameters, Battery status, Automatic Identification System…).

Many modern outboard engines are certified for connection to NMEA-2000 networks. These modern engines transmit data about themselves to the network, where the data can be received by a variety of devices, processed, and displayed to an operator. An engine with NMEA-2000 certification will send data to the network. Once the data is on the network, there can be multiple devices listening for this data, and the same data can be displayed on several instruments or screens and in multiple places. The data can even be ingested and logged by a data logger. In the beginning of NMEA-2000 there were a limited number of engines which provided a NMEA-2000 port, and it was typical that the engine manufacturer would also provide the instrumentation to receive the data from the network. As the NMEA-2000 protocol became more popular, a variety of manufacturers began to produce NMEA-2000 instruments which could receive engine data from a network, and it is now common that data from an engine will be received and displayed on a device made by another manufacturer.

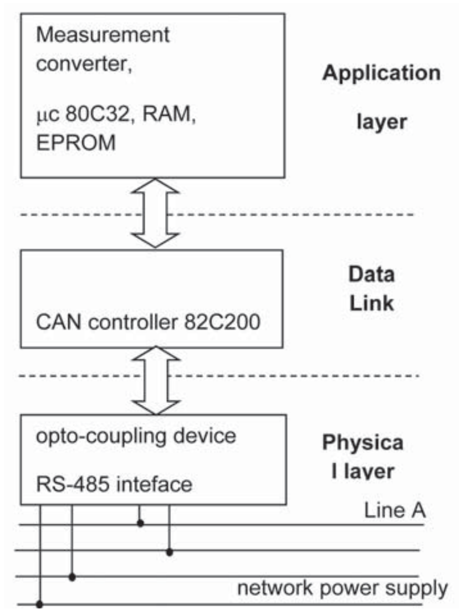


Figure 9 An example how a measuring device is connected to the network [10]
Slika 9. Primjer spajanja mjernog uređaja na mrežu [10]

AN EXAMPLE OF COMMUNICATION NETWORK ON BOARD THE SHIP / *Primjer komunikacijske mreže na brodu*

By using the NMEA 2000 network navigator has the ability to monitor and control propulsion, power systems, state of the ship liquids containers, rudder deflection and insight into navigational instruments essential for the safety of navigation. All these functions are used in order to allow easy and safe navigation. Insight into the key parameters of a vessel can be achieved with multiple server stations. Important data can also be transmitted to a shipping company via satellite communications. Figure 10 shows a schematic example of application NMEA 2000 network onboard the ship.

Monitoring of all critical parameters of a vessel can be carried out through computer screens that have the possibility of detailed adjustments. Figure 11 is an example of the screen appearance.

An example of integrated navigational system on the yacht is built of some standard elements (see fig. 12):

- converters that enable the computer to connect to the NMEA 2000 network
- converters that allow connection of NMEA 2000 network with J1939 network
- adapter to connect the encoder rudder
- adapter for connecting fuel level indicators, water, wastewater, etc.
- depth encoder, speed and temperature encoder
- GPS antenna and receiver
- gyrocompass
- weather stations, etc.

Connection between the PC and the NMEA 2000 network is a NMEA / USB converter. In this way it allows monitoring and control of the vessel from a computer that has a built-in navigation software. Afore mentioned converter automatically converts the NMEA 2000 messages into NMEA 0183 for older sinks which require receiving NMEA 0183 messages.

In the NMEA 2000 network it is possible to implement a multi-function color screen with different views of the state as indicated by figure 11. The screens are connected directly to the network and display one or more parameters to ship encoder with programmable video and audio alarms.

Monitoring propulsion, power systems and other relevant parameters is enabled via the converter and adapter input adapted to NMEA 2000 network. For example, there is the possibility of installing aJ1939/NMEA 2000 converter which provides information on all important parameters of the propulsion and power systems over a single cable. By connecting this device to the GPS antenna / receiver you get a system that

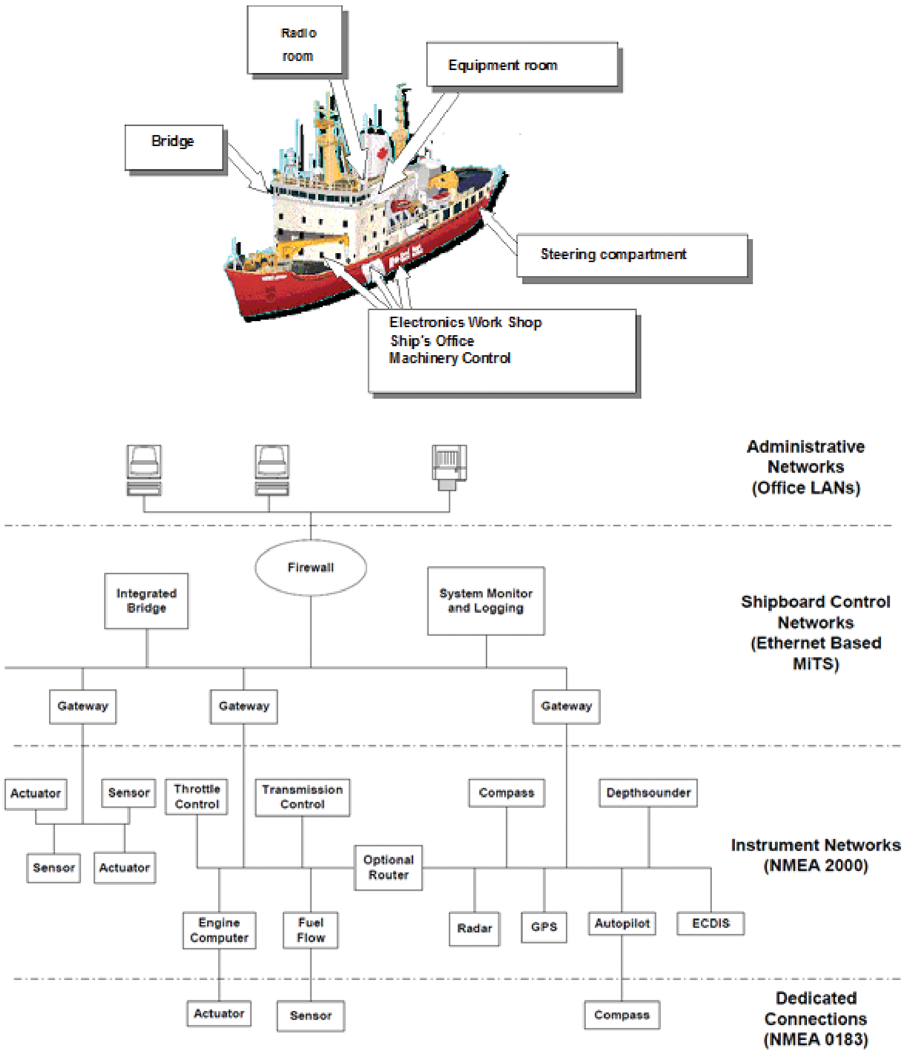


Figure 10 An application of NMEA 2000 network onboard the ship [14]
Slika 10. Primjena NMEA 2000 na brodu [14]

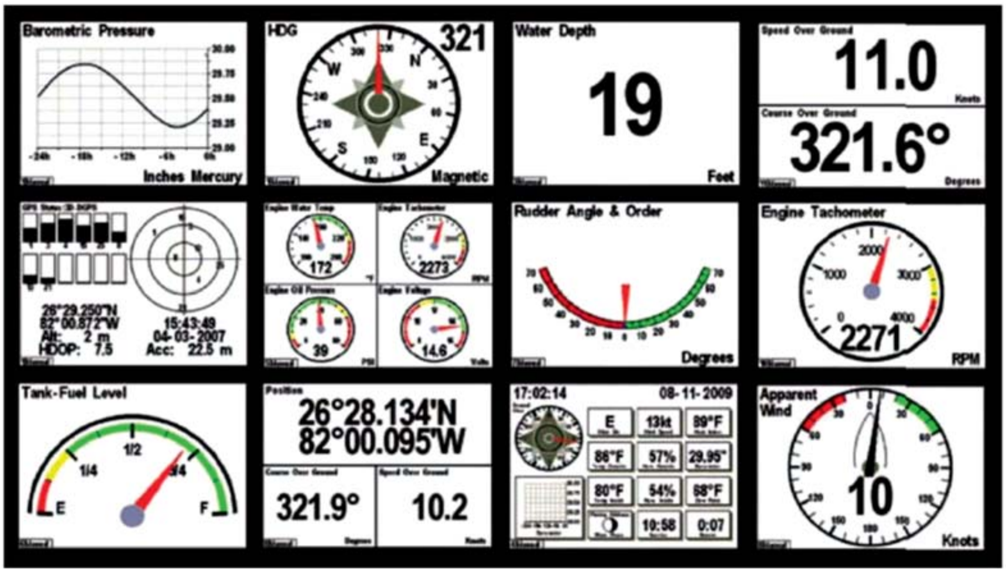


Figure 11 Multi-function color screen [14]
Slika 11. Zaslon sa više prikaza [14]

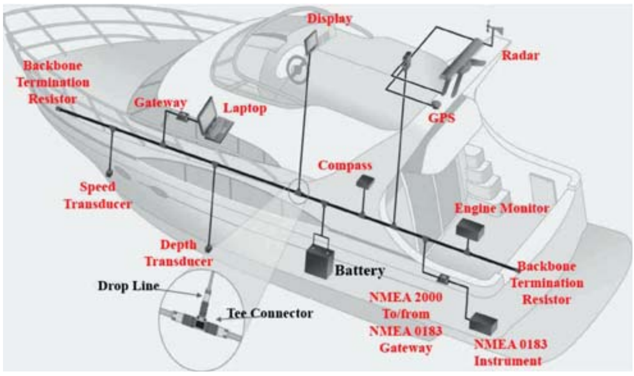


Figure 12 NMEA 2000 Instalation onboard the yacht [14]
Slika 12. NMEA 2000 na jahti [14]

determines the fuel consumption per mile.

If the monitoring and control system operating the complex way, enabling analog signal output, one can install a device that converts analog signals (such as water temperature or oil pressure) to NMEA 2000 network. Further, the converted signal can be used for display on a particular station or server to activate audible and visual alarms. NMEA 2000 network is compatible with the existing electric network control and management so it is not necessary to remove the existing display.

Tank level indicators that are available on the market may be connected through the appropriate adapter to the NMEA 2000 network. This enables control of tank levels from any ship screen compatible with NMEA 2000 network. Calibrating the adapters in 16 control points it is possible to measure states of irregular

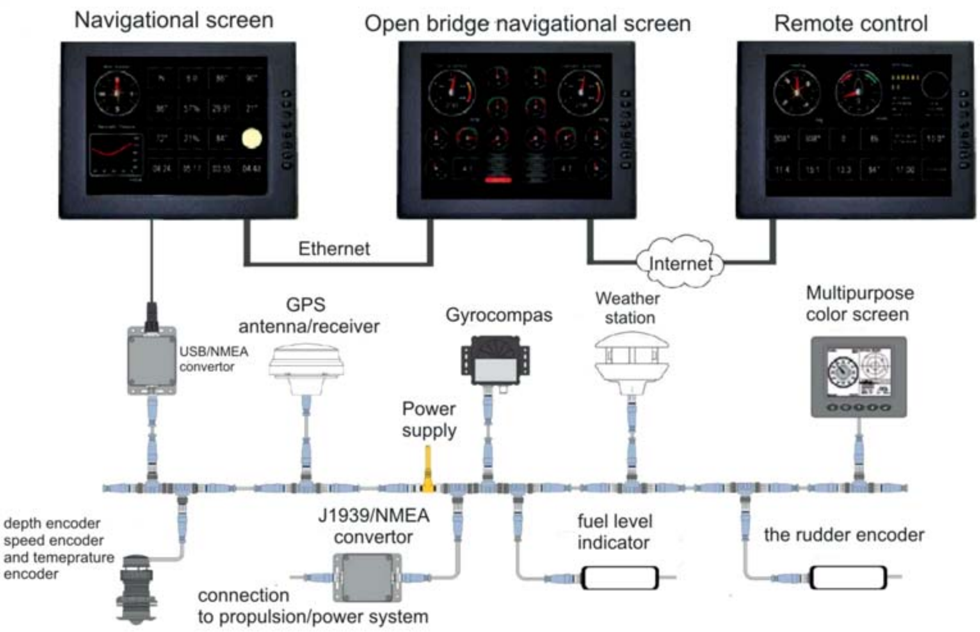


Figure 13 An example of the yacht network with monitoring possibilities [14]
Slika 13. Primjer mreže na jahti sa mogućnostima prikaza [14]

tanks, which is not the case with most conventional encoder tank levels.

Data on the rudder deflection can be transmitted in NMEA 2000 network using a suitable adapter. An analog display can be used to display within the NMEA 2000 network. The adapter has the ability of electronic calibration and does not require mechanical calibration.

The parameters of the AC power system can be transferred to the NMEA network. Battery Monitoring System is isolated with opto-isolators from the reference system so that there is no possibility of impact on the NMEA 2000 network. Parameters such as voltage, electric current, frequency, real power, reactive power, power factor, total production and energy consumption can be traced with the NMEA indicator. Condition of DC power system, can also be tracked in NMEA network. Advanced electronic system for monitoring is used to measure voltage and current DC of sources and consumers. This unit has enabled monitoring of DC generators, batteries, solar panels and wind generators, DC refrigerators and other DC consumers. When the device is used to monitor battery, advanced hardware and software algorithms monitor battery temperature, load, current and charge voltage to determine battery charge status and remaining time the battery can power the network (see fig. 13).

Combining indicator modules we can monitor the state of safety equipment (e.g. temperature, smokiness, the presence of carbon monoxide, explosive gases, etc.) and safety systems (such as motion detection, glass break, closed the door, detection of water leakage). Obtained signals are used to activate an alarm so the crew can react to potential danger in time.

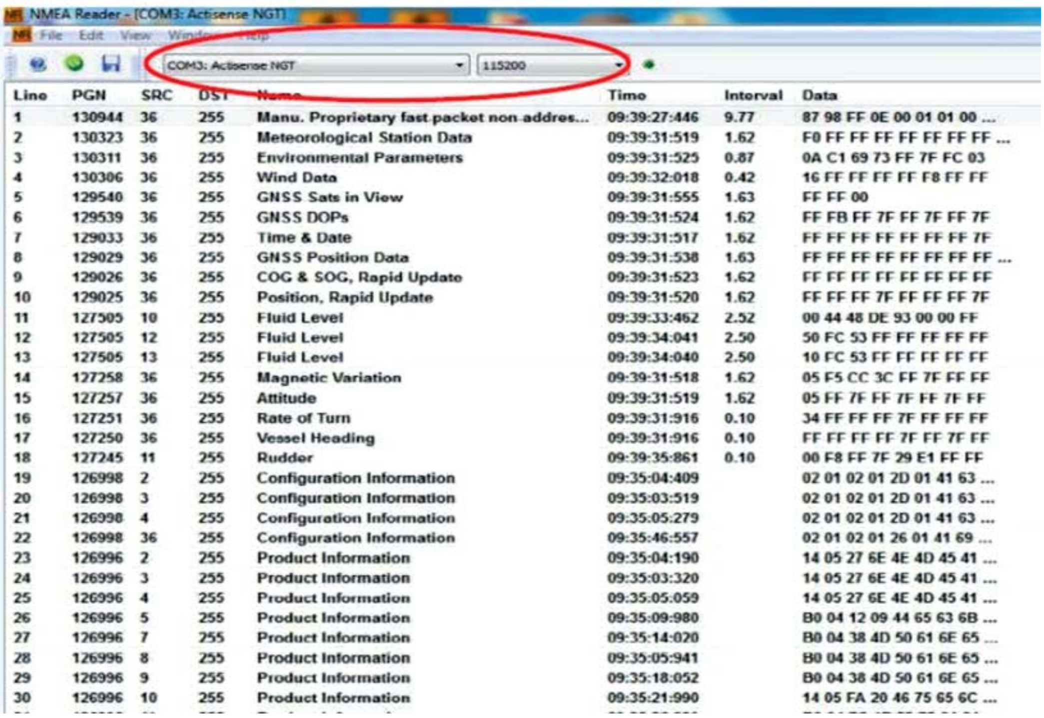
Temperature module measures and provides information of the status of six temperature probes. The temperature range of the encoder is -20ºC to +80ºC C for use in cabin, engine, radiator, fluid tanks, pumps, etc. Thermo-couple probes are used to measure the exhaust gas temperatures (the temperature range of 0 º C to 900 º C). All components of the integrated navigation system are connected with appropriate cables and connectors. Devices are connected through wires to the main power line. All connectors are waterproof to prevent corrosion compounds.

Figure 14 Actisense NGT-1 [16]
Slika 14. Primjer sučelja Actisense NGT-1 [16]

MAINTENANCE AND SERVICE MANAGEMENT POSSIBILITIES / *Održavanje i mogućnosti upravljanja*

NMEA Reader / *NMEA čitač*

The NMEA Reader is a great utility for testing and evaluating a NMEA 0183 or NMEA 2000 system. The program is free to download from e.g. Actisense web site and will work great with a compatible serial or USB adapter, see fig. 14. This software will allow the user to view real time data flow and buffer rates. Certain Actisense gateways can be programmed by this



Line	PGN	SRC	DST	Name	Time	Interval	Data
1	130944	36	255	Manu. Proprietary fast packet non addres...	09:39:27:446	9.77	87 98 FF 0E 00 01 01 00 ...
2	130323	36	255	Meteorological Station Data	09:39:31:519	1.62	F0 FF FF FF FF FF FF FF ...
3	130311	36	255	Environmental Parameters	09:39:31:525	0.87	0A C1 69 73 FF 7F FC 03
4	130306	36	255	Wind Data	09:39:32:018	0.42	16 FF FF FF FF F8 FF FF
5	129540	36	255	GNSS Sats in View	09:39:31:555	1.63	FF FF 00
6	129539	36	255	GNSS DOPs	09:39:31:524	1.62	FF FB FF 7F FF 7F FF 7F
7	129033	36	255	Time & Date	09:39:31:517	1.62	FF FF FF FF FF FF FF 7F
8	129029	36	255	GNSS Position Data	09:39:31:538	1.63	FF FF FF FF FF FF FF FF ...
9	129026	36	255	COG & SOG, Rapid Update	09:39:31:523	1.62	FF FF FF FF FF FF FF FF
10	129025	36	255	Position, Rapid Update	09:39:31:520	1.62	FF FF FF 7F FF FF FF 7F
11	127505	10	255	Fluid Level	09:39:33:462	2.52	00 44 48 DE 93 00 00 FF
12	127505	12	255	Fluid Level	09:39:34:041	2.50	50 FC 53 FF FF FF FF FF
13	127505	13	255	Fluid Level	09:39:34:040	2.50	10 FC 53 FF FF FF FF FF
14	127258	36	255	Magnetic Variation	09:39:31:518	1.62	05 F5 CC 3C FF 7F FF FF
15	127257	36	255	Attitude	09:39:31:519	1.62	05 FF 7F FF 7F FF 7F FF
16	127251	36	255	Rate of Turn	09:39:31:916	0.10	34 FF FF FF 7F FF FF FF
17	127250	36	255	Vessel Heading	09:39:31:916	0.10	FF FF FF FF 7F FF 7F FF
18	127245	11	255	Rudder	09:39:35:861	0.10	00 F8 FF 7F 29 E1 FF FF
19	126998	2	255	Configuration Information	09:35:04:409		02 01 02 01 2D 01 41 63 ...
20	126998	3	255	Configuration Information	09:35:03:519		02 01 02 01 2D 01 41 63 ...
21	126998	4	255	Configuration Information	09:35:05:279		02 01 02 01 2D 01 41 63 ...
22	126998	36	255	Configuration Information	09:35:46:557		02 01 02 01 26 01 41 69 ...
23	126996	2	255	Product Information	09:35:04:190		14 05 27 6E 4E 4D 45 41 ...
24	126996	3	255	Product Information	09:35:03:320		14 05 27 6E 4E 4D 45 41 ...
25	126996	4	255	Product Information	09:35:05:059		14 05 27 6E 4E 4D 45 41 ...
26	126996	5	255	Product Information	09:35:09:980		B0 04 12 09 44 65 63 6B ...
27	126996	7	255	Product Information	09:35:14:020		B0 04 38 4D 50 61 6E 65 ...
28	126996	8	255	Product Information	09:35:05:941		B0 04 38 4D 50 61 6E 65 ...
29	126996	9	255	Product Information	09:35:18:052		B0 04 38 4D 50 61 6E 65 ...
30	126996	10	255	Product Information	09:35:21:990		14 05 FA 20 46 75 65 6C ...

Figure 15 NMEA Reader 15 [16]
Slika 15. Grafičko sučelje NMEA čitača [16]

software such as the NGW-1 and NGT-1. Manufacturer and LEN numbers can be obtained from this software for certain NMEA 2000 devices.

The NMEA Reader is a good utility to read which NMEA compatible devices are located on the network. The data shown includes the specific PGN, Sentence Name, Transmit Interval and the actual data itself.

The top selected item shows the com port, description and baud rate of the available NMEA 0183 or NMEA 2000 Device; see fig. 14. The interval shows how often the data is being sent from the device. This allows the user to know how fast a sender is transmitting; see fig 15.

The bus load can be used to check how many devices are on the network. If the NMEA 2000 network is not functioning correctly it could be due to excess load or a defective sender. The NMEA 0183 version allows for the same reading.

This item shows which instance is assigned to the device allowing for the user to match it on the display. Also, detection of the serial number and function can be helpful for identification of the device.

Sail Soft NMEA Studio

The Sail Soft program will allow data to be sent from a PC via NMEA 0183 on a user selected Com Port. This will allow for testing of displays or networks by sending out select amounts of data which is controlled through the software, see fig. 16.

The data that is being transmitted via NMEA 0183 can then be converted to NMEA 2000 using either an NGW-1, AT-10 or any other NMEA approved device.

For example the Actisense NGW-1 is a great way to convert the data sent from the Sail Soft program into a NMEA 2000 Format. It can also send AIS information into a Bus with the proper Firmware update provided from the Actisense website.

NMEA Analyzer / *NMEA analizator*

The Maretron N2K Analyzer Software is free to download from the Maretron Web site and offers many valuable options for network evaluation and testing.

The N2K Analyzer requires the use of a Maretron USB100 Gateway to properly connect to a NMEA 2000 system; see fig. 17.

Figure17 N2K Analyzer requires the use of a Maretron USB100 Gateway [16]

Slika 17. N2K analizator zahtijeva upotrebu Maretron USB100 poveznika [16]

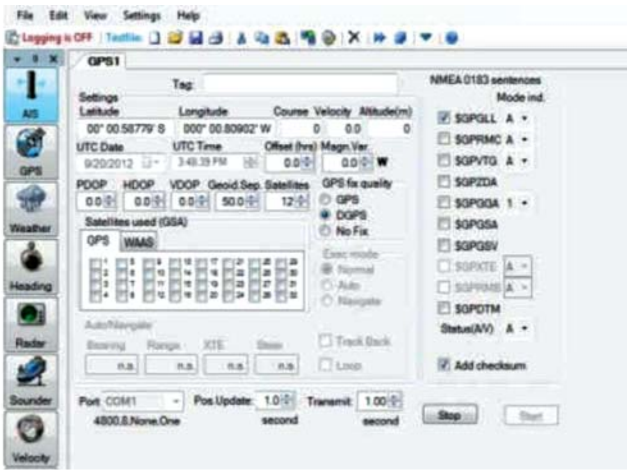


Figure 18 An example of NMEA Analyzer possibility [16]

Slika 18. Primjer analize pomoću NMEA analizatora [16]

Maretron's software will allow a user to assign device instances to components directly. The software also shows software version, manufacturer, serial numbers and much more data specific to a sensor.

The Maretron USB100 Gateway will allow the NMEA 2000 network to be accessed by the N2K Analyzer to show what devices are attached. The Gateway will also allow devices to be programmed for instances and queried for transmitted and received PGN's.

The Main Device page will show what devices are connected to the Network and the specific information of that device.

The unique instance tab allows for the user to view and assign specific instances to a sender if there are multiple versions of the same unit on the network.

The Instancing tool is as simple as setting the number for any applicable device.

The PGN Page shows all transmitted and received sentences to ensure proper operation. The Received PGN Page shows the specifics of what data is being sent and specifics of that data. The transmitted PGN Page will allow for the user to view the live data coming from a sensor which will show if it is actually transmitting and if the data

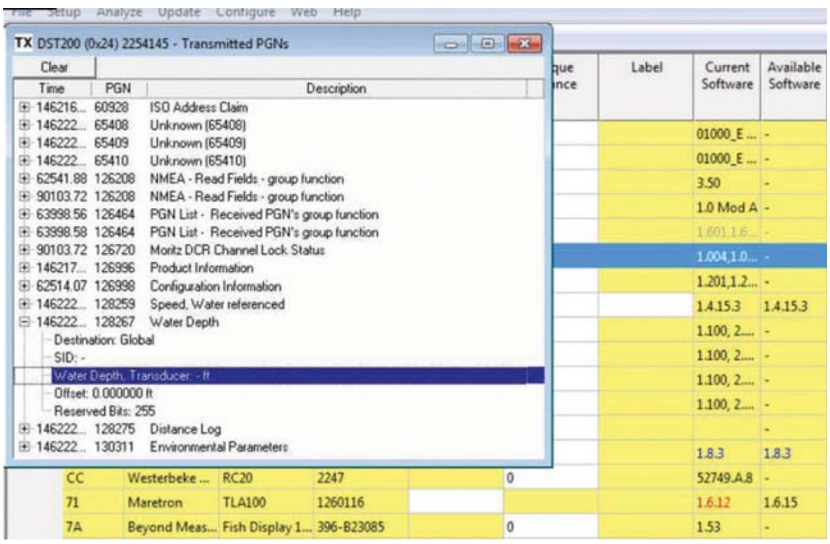


Figure 16 An example of NMEA Studio

Slika 16. Primjera alata NMEA Studio

is correct, see fig. 18.

N2K Analyzer also offers the ability to simulate a DSM250 display through the software to view live data as well as change settings just as if a live display were onboard.

NMEA Builder / *NMEA mrežni dizajner*

Maretron's unique N2K Builder program allows dealers and installers to design and test networks before any cable is pulled through the vessel, see fig. 19.

The software will calculate voltage drop, connector gender, and cable lengths as well as allow the use of custom parameters to meet most design needs.

When used properly, a configuration file can be generated to create a bill of material that will include all Maretron parts used in the build that makes ordering parts much more efficient. There is possibility of detailed view of how the system can be used to partition specific sections of a vessel and show possible connection and integration points. The more detailed a customer's requirements are, the more data can be added to the builder file. This also helps generate a very specific BOM to give an accurate estimate of what parts will be required as well as total component cost.

NMEA Meter / *NMEA mjerač*

The N2K Meter has the capability to test the physical aspects of a network.

Faults that can be detected by the N2K Meter include:

- Opens and Shorts
- Incorrect Topology
- Bad Nodes
- Bad Termination
- Improper Shield Connection
- Intermittent Problems
- Excessive Scan Rate
- Common Mode Voltage

The meter offers the ability to use an Auto-Search tool that will allow the dealer to locate faults.

It works by examining all measurements and then pinpointing any that exceed or are close to specified limits, see fig. 20.

The N2K Meter tracks network data transmission errors in real-time and lets you know if the error rate is acceptable, marginal or unacceptable with the use of a simple signal interface.

Any error rate greater than zero is undesirable (although your network may still function since CAN automatically retransmits after errors).

An error rate greater than 10/s indicates a problem that should be investigated.

The N2K Meter uses unique technology to accurately determine which node was attempting to transmit when a bus error occurs.

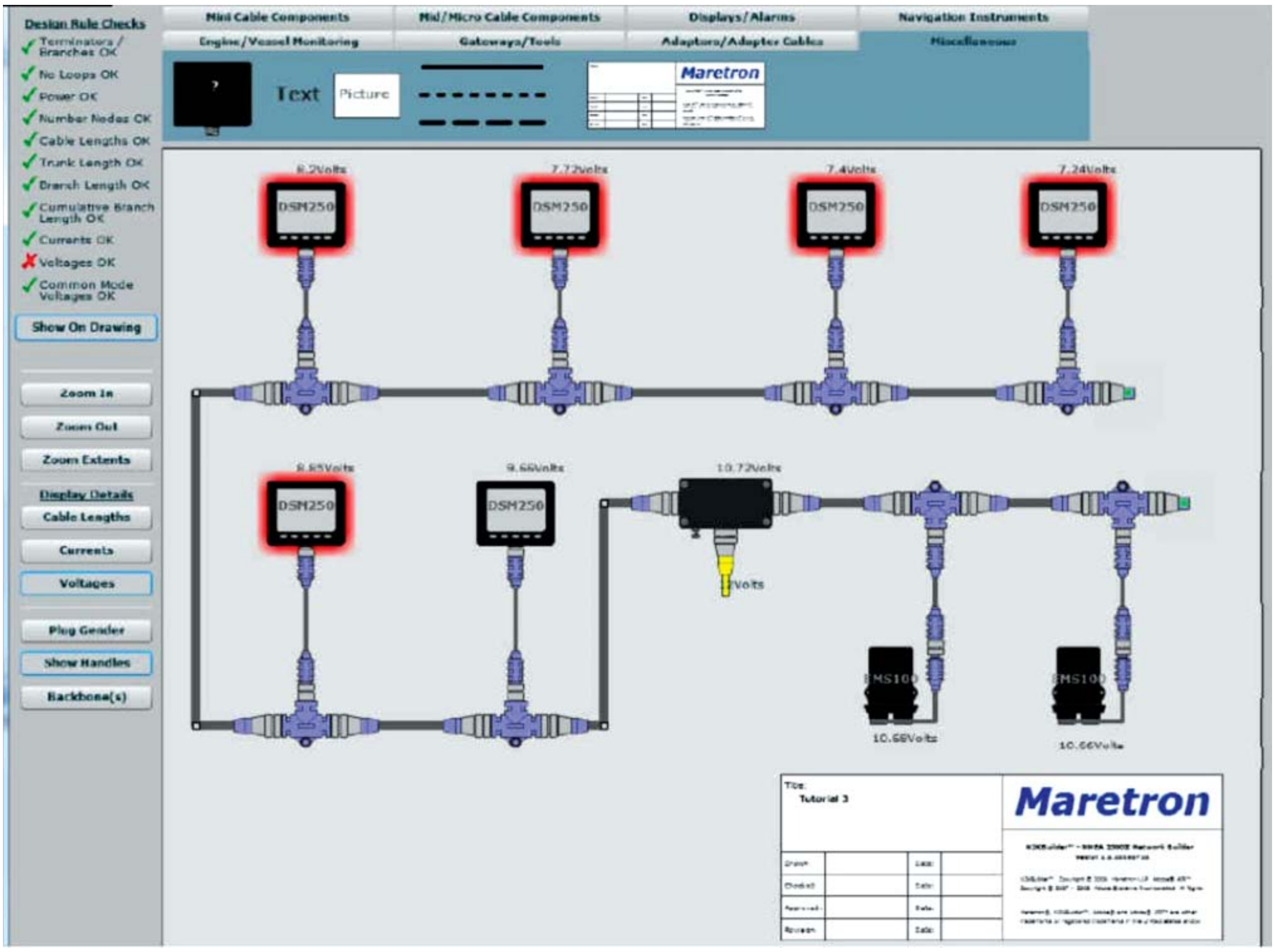


Figure 19 An example of NMEA Builder softweare package [16]

Slika 19. Primjer NMEA Builder software paketa [16]

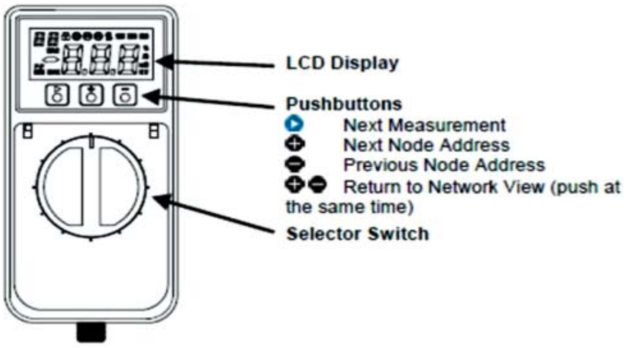


Figure 20 An example of NMEA meter [16]
Slika 20. Primjer uređaja za mjerenje NMEA [16]

CONCLUSION / *Zaključak*

The paper discusses the communication protocol of the integrated navigation system, NMEA 2000, which is designed to enable two-way communication between the devices and viewing the data from different navigation devices, sensors and adapters. Every device connected to the NMEA 2000 network broadcasts its identifier, status and data. All the information is generated in an accurate standardized way to make devices from different manufacturers interpret and display them. On the main power cable NMEA 2000 network can connect devices that are not directly related to navigation (such as level indicators for fuel level, status indicators for main and auxiliary machinery) to serve the navigator in making quality decisions from a centralised place, to guide the ship in the best, shortest and safest way.

Today the focus is on hardware when the real cost in the future system will be software and maintaining data formats. Data transfer rate on a specified two wire bus length at declared safety is a limited parameter. Higher network capacity is thus achievable through optimisation of electronic equipment organisation and transfer and shape of the data.

Expectations about the new industrial standard are high:

- long validity as an international onboard vessel LAN standard since ship safety is greatly taken into account
- CAN error handling is not adaptive procedure and thus sometimes takes longer than other protocols, as long as error detection will be more important than error handling - low cost CAN microcontrollers are natural solution
- use of standardised onboard vessel LAN for real-time control for the distributed systems will be even more applied, after further clock synchronisation on all nodes.
- simple reconfiguration of the network will keep NMEA 2000 standard in use.

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